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STATE GEOLOGICAL SURVEY OF NORTH DAKOTA

FOURTH BIENNIAL REPORT

A. G. LEONARD, PH. D., STATE GEOLOGIST

BISMARCK
PUBLISHED FOR THE STATE GEOLOGICAL SURVEY
1906

c.

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Badlands at head of Deep Creek, about eight miles northeast of Gladstone, known as "The Fairy Dells." The white clays of the Tertiary are here well shown.

ADMINISTRATIVE REPORT

ADMINISTRATIVE REPORT

University, N. D., December 20, 1906.

Hon. George E. Towle, President Board of Trustees of the University of North Dakota:

Sir: I have the honor to submit herewith my report of the work of the State Geological Survey of North Dakota during the past two years.

Early in 1905 the Third Biennial Report of the Survey was published. Several weeks in January were spent at Bismarck supervising the printing of the report. Later the volume was widely distribuated throughout the state and was also sent to those geologists and public libraries of the country from whom requests were received in response to notices sent them.

The State Geologist spent nearly four months during the summer of 1905 in field work, having charge of a United States Geological Survey party which studied the lignite deposits of North Dakota and eastern Montana. The greater part of the season was spent in this state in certain areas which had not previously been carefully examined. The party spent several weeks in southern Billings county, where many thick beds of lignite were located, and also worked in Bowman, Hettinger, Dunn, McKenzie and Williams counties. Many samples were collected and sent to the Coal-Testing Plant of the United States Geological Survey at St. Louis for analysis. Later in the season we followed up the Yellowstone river from its mouth as far as Miles City, locating many lignite beds which are exposed along that river.

While my party was working on the lignite deposits a second party in the employ of the State Geological Survey and in charge of Mr. C. H. Clapp, a graduate of the Massachusetts Institute of Technology, was making a careful and detailed study of the clays, particularly in the region of which Dickinson is the center, and where, perhaps, the highest grade clays of the state are found. Good brick clays and materials suitable for other products are not, however, confined to this district, but have a wide distribution over North Dakota. The white, high grade clays were found to cover

a large area, extending north across the Little Missouri to the Indian reservation, east a few miles beyond Hebron, south nearly to the North Fork of the Cannon Ball river, and west to the divide separating the streams flowing east into the Missouri from those flowing west into the Little Missouri. The clays lie at an elevation of from 2,450 to 2,600 feet above sea level and are confined to the tops of the higher ridges and divides of the region, having been eroded elsewhere. They have a maximum thickness of about 150 feet and cover an area of nearly 4,000 square miles. These white clays overlie the lignite-bearing beds, practically all the coal of the region occurring at a lower horizon, and are doubtless considerably younger than the strata containing the lignite.

Mr. Clapp was assisted in the field work by Messrs. Herbert A. Goodall and Marshall Brannon of the University and many of the illustrations in the report are from photographs taken by Mr. Goodall.

Several hundred samples of clay were collected in the field and during the year were carefully examined and tested in the laboratory by Mr. Clapp. Analyses were also made of many of the clays by Professor Babcock and Miss Bisbee.

During the past summer Mr. Clapp visited all of the clay plants of the state in order to secure full information concerning them, including the methods employed in manufacturing their various products. Additional clay samples were obtained for analysis and testing, together with specimens of brick and tile. The latter were tested to determine their strength and durability.

There are at present twenty producing clay plants in North Dakota, and the industry is in a prosperous condition, most of the companies having all the business they can handle. Several large new plants have been established during the past two years, including those at Grand Forks, Walhalla, Hebron and Wilton.

The Fourth Biennial Report of the Survey contains the results of the investigations made on the North Dakota clays by the several members of the Survey staff since its organization.

The thorough familiarity of Professor E. J. Babcock of the State University with the clays of the region, gained through many years of experimental work on them, has been of much service in the preparation of this report. Of special value is his discussion of the practical tests made by eastern potteries and brick plants in the manufacture of a great variety of wares from North Dakota clays. These included many kinds of pottery, terra cotta and pressed brick

which were made for exhibition at the World's Fair at St. Louis. These products show the possibilities of our clays, even for the production of the higher grades of clay ware.

Thorough tests of a large number of carefully selected samples were made by Mr. C. H. Clapp in the laboratory of the School of Mines of the University. These involved much time and labor for their completion, since 150 samples from all parts of the state were examined and tested as to their structure, hardness, texture, plasticity, shrinkage and strength. Burning tests were also made to determine the color, strength, shrinkage, hardness and absorption of the clays burned at different temperatures, together with their fusibility.

These physical tests were supplemented by the chemical analysis of many samples, this work being done by Miss Bisbee under the direction of Professor Babcock.

The larger portion of the report has been prepared by Mr. Clapp, who deserves much credit for the care and thoroughness with which he has performed the task.

It is believed that this volume on the clays of North Dakota will be of interest and value to the people of the state. Every effort has been made to have the entire report of practical value to everyone interested and to call attention to the great clay resources of the state. It will also make known to outside investors and others the value and possibilities of the clays of North Dakota. The increased use of clay products during recent years cannot fail to result in a steadily increasing demand for this class of goods in the future and in the opening of many new clay plants. The report is intended to help the development of the clay industry of the state.

I spent several weeks during June and July of this year in a careful study of the geology of the Pembina Mountain region. This area is of great interest both on account of its valuable clays and cements and because here are exposed, along the deep valleys of the Pembina, Little Pembina, Tongue and other rivers, geological formations which appear at the surface nowhere else in the state. The character, relationships, thickness and distribution of these were determined and much information gathered concerning them.

Late in July I went to Dickinson and again took charge of a United States Geological Survey party which continued the study of the lignite area of North Dakota, Montana and Wyoming. The greater portion of August and September and part of October was spent in field work in eastern Montana, in the little known and

thinly settled region between the Missori and Yellowstone rivers. The results of the work of the past season in Montana throw new light on several difficult problems of the geology of North Dakota and illustrate the value of the opportunity afforded the State Geologist to extend his field investigations beyond the limits of his own state. The age of the lignite-bearing beds of North Dakota has long been a disputed question among geologists and it is of the greatest importance that the age and relationships of the formations be determined. But they can best be studied in eastern Montana, where their relation to formations of known age is well shown and where they yield abundant fossils. While engaged in work for the United States Geological Survey the past two seasons much material was gathered on the lignite area as a whole, and the North Dakota deposits were compared with those of neighboring states. Through a study of the larger area and the discussion of the various questions which arose with the geologists of the Federal Survey, many new facts and suggestions were gathered with reference to the coal-bearing formations of North Dakota which could not otherwise have been secured.

The results of the work of the State Geologist will be published by the United States Geological Survey in a bulletin on the lignite of North Dakota. This report will contain the results of the interesting and valuable tests made at the government Coal-Testing Plant at St. Louis on the lignite of the state. In addition to the many small samples sent in for analysis, several car loads of coal were shipped to St. Louis and the lignite was tested as to its gas-producing qualities. Of the entire number of coal samples that were examined from all over the United States, the lignite of North Dakota was found to be the best as a source of producer-gas, yielding more gas and better gas than any other fuel tested. This means that the lignite deposits of this region are capable of supplying almost unlimited power if the coal is first converted into gas and then used to run gas engines. It was largely the surprising and remarkable showing made by the lignite from North Dakota in the gas tests at St. Louis which led the United States Geological Survey to undertake the investigations which have been carried on during the past two years. The coal resources of the state could scarcely be more effectively made known throughout the country than in the report soon to be published by the Federal Survey.

Early in June I made two trips to McLean county to examine a number of pieces of university and school lands which had been

offered for sale, in order to determine whether they were coal lands. A brief report to the board was prepared, giving the results of the examination.

One of the subjects to be taken up and investigated during the next two years will be cements and cement materials. North Dakota has valuable deposits suitable for the manufacture of cement, and these deserve careful study. Work on the coal-bearing beds of the western part of the state will be continued and the effort made to determine their age by means of fossils collected from many localities.

The detailed mapping and examination of certain selected areas, such as a county, will be undertaken in the near future. Its surface features, geological formations and natural resources will be carefully investigated. The topographic maps of the United States Geological Survey will be of the greatest service in this detailed work on special areas. Last year a party was at work in the vicinity of Bismarck, mapping that region, and this season a quadrangle lying just east of Williston has been mapped. By means of the topographic map of the latter area its lignite beds can be correlated and their number and extent determined. The geology of the district can also be mapped in detail and the distribution of the formations accurately shown.

The Federal Survey bears all the expense of this topographic work in North Dakota, but the state receives the benefit of the excellent maps that are published. Many states, such as New York, Ohio and Illinois, bear part of the expense of preparing these maps, and it would be greatly to the advantage of North Dakota if it followed their example. The work of mapping within the state would then be pushed much more rapidly than at present, and several quadrangles could be covered in a season instead of one or only part of one. But a larger appropriation for the State Geological Survey is necessary before such co-operation is possible. The State Geologist and the Director of the Agricultural College Survey are consulted as to where the mapping shall be done.

Respectfully submitted,

A. G. Leonard,
State Geologist.

PART I

CLAY AND ITS PROPERTIES WITH SPECIAL REFERENCE TO NORTH DAKOTA CLAYS

BY

C. H. CLAPP AND E. J. BABCOCK.

CLAY AND ITS PROPERTIES WITH SPECIAL REFERENCE TO NORTH DAKOTA CLAYS

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CHAPTER III.—PHYSICAL PROPERTIES OF CLAY.

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CHAPTER I.

THE ORIGIN OF CLAY.

BY C. H. CLAPP.

Definition.—Clay is a term applied to any earthy material which when wet is capable of being moulded into any desired shape, this shape being retained in drying. This property is called plasticity. When clay is heated to a high temperature it becomes hard and strong. Clays are usually fine grained, the plasticity commonly increasing with the fineness. The fineness of the clay is not, however, the cause of its plasticity.

All clays contain what is known as the clay substance or clay base. This base is called kaolin, being made up principally of the mineral kaolinite. Kaolin possesses a high degree of plasticity and it is due to its presence that clays have this property, the plasticity of the clay being roughly proportional to the amount of kaolin present. This varies greatly, as well as the mineral composition of the clay. Quartz, in the form of fine sand, is one of the chief minerals in addition to kaolin composing a clay. The other minerals, chiefly oxides, carbonates and hydrous minerals, are considered as impurities.

ORIGIN.

Clay or rather kaolin, the clay base, is a secondary material, that is, it results from the breaking down of original or primary substances. All rocks, when exposed near the earth's surface, are acted upon by various agents, both mechanical and chemical, and these tend to destroy the primary minerals composing the original mass, and also the original structure of the rock. Thus are formed secondary minerals and structures. Kaolin is one of the most important of these secondary minerals resulting from such decomposition. The structure changes, and hard massive rocks break down into unconsolidated, fine, earthy material. Clay is thus derived by the mechanical and chemical decomposition of rocks, a process called weathering.

Rocks are broken up by several mechanical means. Change of temperature tends to hasten this disintegration. If the temperature

rises the surface becomes hotter than the interior, and therefore expands more. If the temperature becomes colder, the surface exposed to this change contracts more rapidly than the interior. This unequal expansion and contraction results in a tendency for the rock to break off in concentric layers. Water finding its way into the cracks and pores may become frozen and thus expanding considerably develops tremendous power, sufficient to break the strongest rocks. Other forces, such as dust laden winds, lightning and plant roots, all tend to break up rocks. Thus they are broken into smaller and smaller fragments by mechanical means, but are not changed essentially in their chemical composition.

By being thus broken up, rocks are prepared for still further decomposition by chemical agents. Rain water enters the cracks and fissures, dissolves the more soluble minerals, and in this way the whole structure of the rock is loosened. Acid gases, such as carbon dioxide, and vegetable acids, dissolved by the rain water in its passage through the atmosphere and soil, tremendously increase the dissolving power of the water. The chemical action is one of oxidation and hydration. That is, the mineral takes up more oxygen, as iron does when it rusts, and water also enters sometimes into its decomposition, forming hydrated minerals. This process of hydration greatly increases the volume of a rock, and tends to break it up mechanically. Chemical action more fully disintegrates the fragments and converts them into soil. Certain constituents of igneous rocks (granites, diorites and others), notably the feldspars, weather or decompose easily, giving a hydrated silicate of alumina as a result. The secondary mineral thus formed is kaolinite, the base of all clays. Other constituents of the rock, such as quartz and mica, decompose less rapidly and are often left in the clays merely as fine fragments, which accounts for the sand and mica usually present. Weathering thus takes place mechanically and chemically, the final result being to break up and decompose the original rock, and to change it into soil and clay.

The loose materials formed in this manner are now in a condition to be transported by water or any other agent of transportation, such as wind or ice. Clay found in situ, or where it was formed, with the parent rock directly below, is called residual clay. Most clays are removed more or less as they are formed. Water falling on the soil picks up the small particles and carries them in suspension, or pushes them down hill. Finally the soil washed down the slope reaches a stream, and is carried along to the river, and

finally to a point where the velocity of the river is not fast enough to carry it any further, and it is deposited. This usually takes places at the mouth of the river, where large quantities of clay accumulate. These deposits are more or less sorted, the larger particles being laid down first in the swifter current, then as the current becomes slower and slower, the clay and sand deposited become finer and finer, until the current is almost nil, where only the finest silt or clay collects. Clays thus formed are the more common types, found at a greater or less distance from their parent rock. They are called transported clays. Clays are thus seen to be the final result of the weathering of rocks, and if found in the place where they were formed are called residual clays, and if they have been removed some distance from where they were formed, are called transported clays.

CLASSIFICATION.

Clays are classified according to their origin or their uses. A classification based on the uses would be long and useless in describing a deposit of clay. Therefore, while clays of the same origin may differ in composition and be used for many different purposes, yet such a classification seems to be the best to employ in describing the actual deposit. In describing the particular clay some sort of a chemical or mineralogical classification should be used, such as suggested by Dr. E. R. Buckley in his report on the clays and clay industries of Wisconsin.

Several classifications, more or less similar in character, and based on the origin, have been suggested. Following Buckley and Ries the following classification will be used in this report in describing the clay deposits:

- Residual clays.
- Transported clays.
  - Water the agent of transportation.
    - Marine.
    - Estuarine.
    - Swamp and lake clays.
    - Flood plain and terrace clays.
  - Ice the agent.
    - Glacial clays.
  - Wind the agent.
    - Loess clays.

DESCRIPTION OF THE VARIOUS TYPES OF CLAYS.

RESIDUAL CLAY.

It has been shown how rocks undergo certain chemical and mechanical changes which form clay and soil, and where this clay is found directly in place it is said to be residual. From the nature of residual clays one would expect to find a natural gradation between hard, unchanged rock at some depth, through a partially broken up and decomposed rock, and finally a true clay, and such is the case in nature. Residual clays are of course superficial, their depth reaching only to the limit of weathering in that locality. Sometimes, however, one finds deposits extending to a considerable distance below the surface, due either to the rock being especially easily decomposed, or due to decomposition by underground waters.

As all shales and sandstones were derived originally from igneous rocks it is only necessary to describe the chemical changes which take place in their decomposition. They are composed of various minerals, commonly one of the feldspars, which are silicates of alumina, potash, soda and lime, together with quartz and certain dark colored minerals, the latter silicates of iron, magnesia and lime. Ferrous iron, magnesia, lime, potash and soda are soluble and are dissolved by percolating waters and carried away. The feldspar is changed to kaolinite, the hydrated silicate of alumina, the quartz remains unchanged, and the dark colored, ferro-magnesian minerals are changed to basic impure koalin, and to other hydrated silicates of magnesia and ferric iron, and also to ferric hydrate, known as limonite or ochre. G. P. Merrill in his "Rocks, Rock-weathering and Soils," gives the following analyses of fresh granite, gneiss and the decomposed product of the gneiss, which illustrate the relative changes.

	Fresh	Decomposed
Silica (SiO_2)	60.95	45.31
Alumina (Al_2O_3)	16.89	26.55
Iron oxide (Fe_2O_3)	9.06	12.18
Lime (CaO)	4.44	trace
Magnesia (MgO)	1.06	0.40
Potash (K_2O)	4.25	1.10
Soda (Na_2O)	2.82	0.22
Phosphoric acid (P_2O_5)	0.25	0.47
Ignition (H_2O)	0.62	13.75
	100.08	99.98

Thus while the decomposition of igneous rocks, which practically always contain some feldspar, furnishes some kaolin or clay base, most residual clays contain enough ferric oxide to color them red. Iron tends also to make them fuse more easily. Magnesia and the alkalies also act as fluxing constituents. However, some residual clays, such as those that result from acid rocks high in feldspar and quartz, notably pegmatite, furnish us with our highest grade kaolin, the quartz, mica and undecomposed feldspar and alkalies being removed by washing. The clays from such rocks have not had a chance to become mixed with harmful ingredients resulting from the decomposition of other rocks, as transported clays have. Therefore, while most residual clays are low grade, the purer deposits are very high grade, furnishing our best china clays.

Residual clays do not accumulate to a great depth except under exceptional circumstances, as they are being continually removed by the run off of water, and carried away and deposited somewhere else, forming transported clays. The southern states abound in low grade residual clays of moderate thickness, which probably once existed in the north. But when the great ice sheet advanced from Canada and extended over the northern part of the United States, these residual clays were all removed and now form a part of the glacial debris. North Dakota is lacking entirely in residual clays. There are no outcrops of igneous rock to furnish them. Possibly before the ice age a small strip of igneous rock was exposed along the eastern boundary, but any clay derived from this has long since been removed by the glacier. These rocks are now covered by over 300 feet of unconsolidated glacial drift, and the sand and clay deposits of old glacial Lake Agassiz.[1]

TRANSPORTED CLAYS.

Residual clays are often removed by some agent of erosion and transportation and deposited at some distance from where they originated, forming transported clays. By this process the residual clays of several localities become mixed together, and thus transported clays are apt to be even more impure. However, transportation and subsequent deposition tends to size the particles, and clay, by being separated from coarse particles, is sometimes made available where it would not have have been otherwise. There are three main agents of transportation, which are, in order of their importance, water, ice and wind.

[1]Babcock N. Dak. Geol. Survey, Vol. I.

Water the Agent of Transportation.—Residual clays washed into a stream are carried along until they reach a point where the velocity of the water is not sufficient to keep the clay particles in suspension. They are then deposited, and in this manner layers of clay are formed which grow in thickness. These layers are of course practically horizontal. With a change of velocity of the water, particles of a different size are deposited over the original layer. It is in this way that such transported or sedimentary clay consists of a series of more or less horizontal layers of different texture and composition, and the material is said to be stratified. Stratification is one of the chief characteristics of clays deposited from water.

A single section of a sedimentary deposit such as is exposed in the cut bank of one of the western rivers of the state, may show thirty of forty layers of different character. Stratified clays as a rule are apt to vary greatly in a vertical direction, but some beds reach a thickness of many feet or even a hundred or more, and the composition and nature of the clay does not change materially. Horizontally the beds vary somewhat but not so much, and layers of essentially the same characteristics often extend over large areas. Such clays are apt to be deposited on an ocean bottom or floor of a large lake. The condition under which clay is deposited greatly influences its nature, and there are several varieties based on this condition.

MARINE CLAYS.

Clays which have been carried by rivers to the ocean and there deposited on the sea floor are called marine clays. Such deposits are fine, as they have been transported by streams and finally carried out into the ocean and laid down in comparatively still water, all coarse material having been left behind. Marine deposits are also of great extent and thickness and are more uniform than other clays. This is due to the fact that they are less subject to change than clays deposited nearer shore, and only movements of a greater magnitude than shifting currents affect them. Horizontally, of course, they may differ, due to a difference of material brought in by neighboring streams, and flowing through countries furnishing different residual clays. This horizontal change is sometimes very rapid, but as a rule the horizontal extent of clay beds of essentially the same character is great in marine clays, far greater than in other sedimentary clays, and the change from one kind of clay to

another is gradual. The Benton and Pierre shales of North Dakota are good examples of marine clays.

ESTUARINE CLAYS.

Estuarine clays are those deposited in long narrow arms of the sea into which one or more rivers usually enter and are called estuaries. Chesapeake Bay is a good example of a modern estuary. An estuarine deposit is necessarily long and narrow, with a basin shaped section transverse to its length. One would also expect to find coarse clay near the narrow or head end of the deposit where the current was swiftest, and the finer material at the wide end. Possibly some of the so-called Laramie clays of the western part of the state are estuarine in character, but these have not been studied sufficiently to trace any such characteristics of their deposition, and probably they belong largely to the next class of clays.

SWAMP AND LAKE CLAYS.

Lake clays are similar in their origin to estuarine clays. Rivers emptying into lakes deposit their sediment in them. The lakes are thus gradually filled up, and after passing through the swampy stage, cease to exist, unless, as is often the case, there is a fluctuation of the water level. Lake deposits are apt to vary a good deal in a vertical direction, since the deposits are subject to many changes of condition which affect the material deposited. Normally the rivers form deltas of gravel and coarse sand near their mouths, and the finer sand and clay are carried out beyond and spread out on the lake bottom in a more or less uniform layer. But in time of flood the rivers are swifter and carry greater quantities of sediment and even some of the coarse particles are deposited over the whole lake. Lake clays are thus affected by climatic conditions, and thin sandy layers, along which the clay parts easily, are common. As the sediment accumulates and the lake grows smaller, the delta deposits push out nearer to the center and are found overlying the fine clay. In the marshy stage, if there is abundant vegetation present, peat is formed, which is changed through geological ages to coal. Such regions are also subject to change of water level and the marsh may again become a lake, and a new series of clay, sand and coal beds may be formed. The deposits of the western part of the state in which the lignite is found, are of this character. The variations and the number of kinds of sediment has already been mentioned. These various deposits are more or less lens shaped, as if deposited in old basins. Along the eastern border of

the state there exists another very common type of these clays. When the great ice sheet covered this country, numberless lakes were formed along its front, and into these were washed the finest part of the debris pushed along by the glacier. Lake Agassiz was one of the largest of these lakes. It occupied what is now the fertile Red River Valley. In this old lake, clays were deposited which are now furnishing the material for most of the common brick made in the state.

FLOOD PLAIN OR TERRACE CLAYS.

Along the larger rivers there are broad flats, sometimes two or more extending along the valley, one above the other, like steps. These are called terraces. The lowest is coverd in times of flood and is therefore designated as the flood plain. The river at such periods of high water carries with it large amounts of gravel, sand and clay, and these are carried over the banks of the channel where the current is swift, out on to the flood plain. Here the current is slackened and the material deposited, usually not assorted to any extent, as the decrease in velocity is apt to be sudden. In protected spots, however, some of the very finest clay is deposited, and thus, while most flood plain clays are coarse and sandy, some of them are very plastic and are good brick and tile clays. In this manner the flood plains of rivers are built up. The terraces rising above are former flood plains, formed when the river was at a higher level. Terrace clays are therefore similar in character to flood plain clays, and both are classed under the general name of alluvium. Many clays having this origin occur in North Dakota, but their use at present is very limited, only two or three brick plants utilizing them.

ICE THE AGENT—GLACIAL CLAYS.

In comparatively recent geological times the northern half of this country was covered by a thick layer of ice. This ice accumulated in the region of Hudson Bay and moved southward under its own weight. In its progress such an agent would naturally remove all residual clays and push them or carry them along with it. Not only did it remove these unconsolidated materials, but it broke off projecting ledges of hard rock, and ground the surfaces of the ledges over which it passed to a powder, leaving the ledges polished and striated. This heterogeneous material it left in its retreat in great irregular dumps called moraines.

Glacial drift or till, unless it has been reassorted by water, is seldom of any economic importance. The clays are tough and non-plastic, and contain large amounts of sand and gravel. G. F. Loughlin in his report on the clays of Connecticut states that the approximate percentages are gravel, 25 per cent, sand 20 per cent, rock flour 40 to 45 per cent, and true clay less than 12 per cent. In localities where the bed rock is shale, glacial clays are of more importance and are used for brick and tile.

Glacial drift may be reassorted by water, and forms an important source of material which may be transported and deposited in lakes and seas, and thus become economically important. Also the fine material of moraines may be washed out of the hills into the hollows between, and some clays formed in this manner are free enough from pebbles to be used for brick. The large amount of lime in glacial clays is another very serious drawback to their use. Glacial clays have been used to some extent for brick in North Dakota, but although they are of great abundance they have little economic value, except for the manufacture of common brick. Where no other clays are available a very good grade of such brick can be made from them.

WIND THE AGENT—LOESS CLAYS.

In the Mississippi basin are large deposits of a peculiar calcareous, silty material known as loess.

Undoubtedly some of these deposits have been formed by winds. Water has played an important part in their formation likewise, and just what division is to be made between the importance of these two agents is uncertain. No clays of this character have been noted in North Dakota.

In the sandy regions in the western part of the state, the winds are important erosive agents, but deposits due to winds are superficial and are sandy rather than clayey in their nature.[1]

[1]See N. D. Geol. Survey, Vol. III, p. 64.

CHAPTER II

THE CHEMISTRY OF CLAY

BY C. H. CLAPP AND E. J. BABCOCK.

Composition.—Clay is composed of the mineral kaolinite mixed with more or less impurities, all of the impure minerals being, of course, in fine particles. The mineral composition depends on the nature of the rock from which the clay was derived, and the amount of weathering. There are two main classes of minerals, original or primary, and secondary. Primary minerals are those which possess the same chemical composition as they did in the parent rock, but have been ground or reduced in some manner to a very fine condition. Secondary minerals are those whose presence is due to chemical action. Quartz, feldspar, mica, the iron ores, such as magnetite and pyrite, calcite, dolomite, gypsum, hornblende and rutile, are the ordinary primary minerals. Kaolinite and limonite are the chief secondary minerals; calcite, gypsum, quartz and pyrite are sometimes also of secondary origin.

The chemical composition of a clay depends of course on the mineralogical composition, and therefore varies within wide limits. The composition of pure clay, or kaolin, corresponds closely to that of kaolinite, that is, it is a hydrated sicilate of alumina. The presence of the other minerals introduces such elements as free silica, iron, lime, magnesia, potash, soda, titanium, manganese, organic matter and certain soluble sulphates and carbonates. These different minerals and elements play an all important part in determining the quality and uses of clay, and will therefore be discussed in detail.

Clay Substance. Kaolinite and Pholerite.—As already stated, the mineral forming the chief part of the clay substance, so called, is kaolinite. The kaolinite is usually more or less impure, occurring in soft, compact, clay-like masses, which possess strongly the peculiar argillaceous odor. These masses in the purer varieties are white, but are ordinarily more or less stained, being yellow, brown, red or blue in color. This massive variety is called kaolin. The mineral is plastic and highly refractory, fusing only at cone 36, which equals 3,362 degrees F.

The chemical formula for kaolinite is $Al_2O_3\ 2SiO_2\ 2H_2O$.

The percentage composition of a typical sample is as follows:

Alumina	39.8 per cent.
Silica	46.3 per cent.
Water	13.9 per cent.

Some flint clays have a higher percentage of alumina than pure kaolinite, and this fact leads to the belief that a mineral called pholerite enters into the composition of clay. Pholerite is similar to kaolinite in its properties, but contains more water and alumina.

It has already been noted how kaolinite is derived from the decomposition of feldspar, and also that the amount of kaolinite present in clay varies greatly. White kaolins are practically pure, containing over 98 per cent of kaolinite, while the sandy, impure clays may have less than 20 per cent.[1] Many of the clays of North Dakota are not very high in kaolinite, some of the purer ones having 60 per cent to 67 per cent. The common brick clays are rather low, especially the Red River Valley clays, some of which contain as little as 22 per cent of kaolinite.

The properties of clay vary according to the percentage of kaolinite present. The addition of other minerals introduces other elements, such as iron and lime, magnesia, alkalies, etc., which combine with the alumina and silica present in kaolinite to form more fusible compounds. That is, these elements are said to play the part of fluxes, and make the clay fuse more easily. Most clays rich in kaolin have a high shrinkage, and in such a case may need to be mixed with sand or feldspar in order to keep the shrinkage low enough to work the material safely and successfully.

Silica.—Silica occurs in clay in two forms, as free, uncombined silica as fine quartz or sand, and as combined silica, in silicates such as kaolinite, feldspar, mica and hornblende. The silica in kaolinite which is combined with alumina and water, is usually designated in an analysis as "combined silica." It is of course an essential compound of pure clay, and not a foreign substance or impurity. The silica which is combined with certain bases to form such minerals as mica, hornblende, etc., as well as the quartz sand, is an impurity and exerts certain influences on the clay. This silica is determined by the proximate analysis, and is called "free silica." The name is misleading as the silica in the silicate minerals is really combined and not free. Ries has therefore proposed the use of the term sand, to include both quartz and silicate minerals, other than kaolinite, or those which are not decomposed by sulphuric acid.

[1]H. Ries, N. J. Geol. Survey, Vol. VI, p. 47.

The amount of silica in combination, in feldspar, mica, hornblende, etc., varies, according to Wheeler, from 0.5 to 6.0 per cent in high grade clays, from 5 to 12 per cent in fair grade clays, and from 10 to 25 per cent in the inferior clays.[1]

The bases of these minerals are strong fluxing agents, while the minerals themselves have an important effect on the properties of the clay, acting in much the same manner as does quartz sand.

Sand acts principally as an anti-shrinkage agent, reducing both air shrinkage and fire shrinkage. It also diminishes the plasticity. It raises the fusing point of clays of low fusibility, but at very high temperatures, when in excess, acts slightly as a fluxing agent.[2] The ordinary basic silicites, however, act as fluxing agents at much lower temperatures (depending on the minerals present) than does pure quartz sand. The effect of the latter is proportional to the amount present and to the size of grain.

The amount of free silica in a clay varies greatly. Wheeler[3] gives 0.5 per cent as a minimum for Missouri clays and 84 per cent as a maximum. The average amount lies between 20 and 35 per cent. Free silica was not determined as such in the analysis of North Dakota clays.

Ries[4] gives the variation of total silica in several classes of clays, the results being determined from several hundred analyses:

	Per cent. of total silica.		
	Minimum.	Maximum.	Average.
Brick clay	34.35	90.877	59.27
Pottery clay	45.06	86.98	45.83
Fire clays	34.40	96.79	54.304
Kaolins	32.44	81.18	55.44

The impure glacial and lacustrine clays of North Dakota are not very high in total silica. In the low grade clays associated with the lignite in North Dakota, which are clays of low fusibility and high shrinkage, the total silica varies from 71.25 to 53.72 per cent, with an average of 59.12 per cent. Only a few analyses of the Cretaceous shales have been made, but they show a wide variation in silica, at least from 29.27 to 69.90 per cent. The total silica in the high grade Tertiary clays ranges from 76.24 to 53.32 per cent, the average being 65.94 per cent. It will be seen by referring to the table given that the clays of North Dakota lie well within the maximum and not far from the average mentioned by Ries. In case

[1] Mo. Geol. Survey, Vol. XI, p. 54.
[2] See discussion on fusibility of fire clays, Part IV.
[3] Mo. Geol. Survey, Vol. XI, p. 54.
[4] Bull, N. Y. State Museum, No. 35, p. 525.

of the higher grades of North Dakota clays, such as the fire and potters clays, especially the latter, the per cent of silica is almost ideal, being no nearly that required for the most successful working that it is not found necessary to add but little if any silica. To illustrate how nearly the average silica content of our higher grade North Dakota clays, i. e., 65.94 per cent, compares with the blended or finished material, the following analyses are given from well known sources: China clay, Cornwall, England, silica 66.20 per cent; clay mixed and ready to use, from a Trenton pottery, 69.03 per cent; unglazed Baltimore stoneware, fine, white, silica 67.40 per cent; fine yellow Wedgewood ware, silica, 66.49 per cent.

Feldspar.—Two of the chief silicates found in clay, other than kaolinite, are feldspar and mica. Feldspar, which is a silicate of alumina with potash, or with soda or lime, or with all these, comes in small, light colored grains, which decompose easily and pass into kaolinite. The North Dakota clays are quite free from feldspar.

Feldspar has at ordinary and low temperatures the same effect as sand, namely, it decreases the plasticity and the air and fire shrinkage up to about 2100 degrees F. when feldspar begins to melt and becomes a strong flux.

Mica.—Mica occurs in most clays in small, thin scales which have a bright luster and are silver white to black in color. Mica is a silicate of alumina, with other elements, such as potash, iron and magnesia. The silvery mica, muscovite, is most common, and does the least harm. The dark mica, biotite, contains iron, so that it more readily weathers, staining the clay and affecting the color of the burned product. The North Dakota clays vary greatly in their mica content. Some are remarkably free from this material, while other samples, especially those from certain horizons in the vicinity of Dickinson, which consist largely of sandy clays, contain a marked amount of muscovite mica, usually in a very finely divided state. For finer wares this mica could in most cases be easily removed by disintegrating the clay in water and passing "the slip" through a 100 mesh screen.

Mica lowers the plasticity a little and decreases the shrinkage. At high temperatures it becomes a powerful flux, thereby lowering the refractory power, especially if in the form of biotite mica.

Alumina.—Alumina being a component of kaolinite, is an essential constituent of clay. It also occurs in feldspar, mica, hornblende and other silicates. The effects of alumina are approximately the

same as those of kaolinite, since in clays alumina always exists in the form of a silicate of similar composition to that of kaolinite. In pure kaolinite the amount of alumina is 39.8 per cent. As stated above, some clays reach this percentage and even higher. North Dakota clays do not contain as high a percentage of alumina as some clays because of a large proportion of silica. The Benton shales average about 17 per cent. The Laramie clays are also low in alumina, ranging from 25.03 to 9.47 per cent, the average being 17.26. The Tertiary clays are somewhat higher, the extremes being 27.83 and 15 per cent, and the average 20.84 per cent.

While North Dakota clays are generally lower in alumina than a pure kaolinite, this is by no means an uncommon condition met with in many high grade clays. Moreover, a pure kaolinite would be too high in alumina content to be used for many purposes without first being blended with a considerable proportion of silica. As has already been observed under the consideration of silica there are many clays in North Dakota which have very nearly ideal proportions of silica and alumina for immediate use and are found by actual tests to work unusually well.

Iron.—Iron is always present to some extent and is very important, because it determines largely the color to which the clay will burn. It occurs in several minerals, the most common in clay being the oxides, magnetite and hematite; the hydrous oxide or limonite; the sulphide or pyrite; the carbonate or siderite; and several iron silicates, notably biotite, glauconite and hornblende. The iron exists in these minerals in two states, namely, as the ferrous and ferric oxides. The iron in ferrous oxide is combined with equal parts of oxygen, giving a compound with the symbol FeO. In the ferric oxide, whose symbol is Fe_2O_3, the iron is combined with one and a half parts of oxygen, and it is therefore in a higher state of oxidation. These two oxides are important, and their effect on the color and fusibility of the raw clay is entirely different.

The amount of iron in clays varies considerably. The iron is usually reported in an analysis as the ferric oxide, regardless of the condition in which it exists in the clay. The range of ferric oxide in clays is given by Ries as follows:[1]

	Minimum.	Maximum.	Average.
Brick clays	0.126	32.12	5.311
Fire clays	0.01	7.24	1.506
Kaolins	trace	6.87	1.29

[1]Bull, N. Y. State Museum, No. 35.

The North Dakota clays are rather low in iron. Even the brick clays are low, most of the brick being cream or light colored, due partly, however, to the large amount of lime. The low fusing point of the coal clays is due to lime and the alkalies rather than iron, the percentage of the latter ranging from 3.16 to 7.47, the average being 4.61. The Benton shales are not very high in iron, for the few which have been analyzed the average being about 5 per cent. The Tertiary clays are very low in iron, considering their great thickness and extent, and they vary from 1.33 to 9.46 per cent, the average being 2.66 per cent.

Iron is the chief coloring agent of both raw and burned clays. When the iron exists in the ferric condition, as in limonite and hematite, the clays are yellow, red or brown. Ferrous iron, present as siderite or pyrite, gives a variety of shades from gray to blue. The color of the so-called blue clays is due partly to iron in the ferrous form and partly to carbonaceous material. Clays which contain iron in the ferrous condition are usually carbonaceous, the carbon, which has a great affinity for oxygen, reduces the ferric iron, or prevents its formation. Many of these blue clays containing iron are yellow or reddish near the surface, or along the cracks through which water and air can penetrate, the ferrous iron having been oxidized to the ferric form.

The color of the burned clay depends not only on the amount of iron present, but, as has been conveniently summarized by Ries,[1] on: (1) the amount of iron in the clay; (2) the temperature of burning; (3) condition of the iron oxide, and (4) the condition of the kiln atmosphere. With a little more than one per cent of iron present clay may burn to cream white; with less than that, to an almost pure white. Clays with 1.5 to 3 per cent burn to a buff or brown at high temperatures, and cream or pink at low. With 4 per cent or over the color is pale red or salmon (the color of underburned brick) when burned at a low heat, and red to purplish at high. The presence of other constituents effect the color of the burned clay very markedly. Moreover, clays of low fusibility burn red at comparatively low temperatures, while refractory clays even if as high, sometimes even higher, in iron, burn to buffs and browns.

This may be illustrated by the burning tests of three clays, the analyses of which show the same amount if iron, 4.98 per cent. The clays are of varying fusibility. The first becomes viscous at 2,400 degrees F, the second at 2,700 degrees F, and the third at

[1]N. J. Geol. Survey, Vol. VI, p. 57.

2,800 degrees F. The clays were burned under similar conditions. The following are their partial analyses:

	I.	II.	III.
SiO	57.22	62.65	62.90
FeO	4.98	4.98	4.98
AlO	19.24	20.76	22.68
CaO	2.26	0.26	0.32
MgO	3.29	0.77	0.72

The burning tests are as follows:

	Cone 05 1922 degrees F.	Cone 01 2066 degrees F.	Cone 5 2246 degrees F.
I.	red	reddish brown	dark brown
II.	pink red	yellowish brown	dark gray
III.	light buff	yellow	gray

The color also depends upon the condition of the iron oxide. The above discussion assumes the iron to be in the ferric condition. If, however, all or part of it, is in a ferrous condition, the color is green, blue or black. The state of the iron depends on the nature of the clay, and the kiln atmosphere. If the clay contains carbon or sulphur, these must be first oxidized, and driven off as gases, before the iron can be oxidized to the ferric state. To oxidize this sulphur and carbon, as well as the ferrous iron, the gases entering the kiln must have an excess of oxygen, and the kiln atmosphere is then said to be oxidizing. If, however, the fires are smoky, there is a deficiency of oxygen, and a reducing atmosphere is formed, and instead of ferrous iron being oxidized. ferric iron, if there is any present, may be reduced to the ferrous condition. The black core of bricks, which have not been sufficiently oxidized during burning, is due to the formation of ferrous oxide or other ferrous compounds.

Iron is also an important fluxing agent, and cannot be present in large amounts in highly refractory clays. The North Dakota fire clays are all under 1.5 per cent of iron, the best under 1 per cent. Ferrous oxide is a very much stronger flux than the ferric. The black, glassy spots seen on paving brick and sewer pipe are due to the ferrous silicate, which fuses to a black, glassy slag.

Pyrite (FeS_2) is one of the most harmful of the iron minerals. It is a bright yellow mineral with a metallic luster, and usually occurs in small granular masses or in nodules. It is formed by the reduction of ferrous sulphate by carbonaceous matter, and is abundant in the clays associated with the lignite, and also in the carbonaceous shales of the Benton and Pierre. In burning, part of the sulphur is driven of as the gas, sulphur dioxide, SO_2, which

has a characteristic stifling odor at a low heat. The rest of the surphur requires a higher temperature and an oxidizing atmosphere to be eliminated. If it is not, the iron is kept in a ferrous condition and slags easily, and the sulphur gases formed after slagging warp and bloat the clay into a porous mass..

Siderite ($FeCO_3$) also occurs in small concretionary nodules or masses, which tend to produce effects sometimes resembling pyrite, although not in so marked a degree. The pyrite and carbonate nodules may occasionally be removed by hand picking or become well mixed in crushing. If they are small and evenly distributed, their harmful effects may often be overcome by proper burning.

Lime.—Lime is a most important fluxing constituent, and when present in large quantities it also effects the color of the burned clay. It occurs in several different forms in clay, the most common of which are the carbonate or powdered limestone, the sulphate or gypsum and the silicate. The amount of lime in silicate minerals is usually very small, or less than 1 per cent. Some clays in regions where gypsum is abundant, have notable percentages of lime from that mineral. This is true of the Cretaceous clays of North Dakota. The most common lime mineral is the carbonate. This is easily detected by putting a drop of hydrochloric or muriatic acid on the raw clay, which attacks the calcite, and liberates carbon dioxide (CO_2) with vigorous effervescence.

Ries gives the amount of lime, which is the oxide of calcium (CaO) ,in several kinds of clays as follows:[1]

	Minimum.	Maximum.	Average.
Brick clays	0.024	15.38	1.513
Pottery clays	0.011	9.90	1.098
Fire clays	0.03	15.27	0.655
Kaolins	trace	2.58	0.47

The North Dakota clays show a great variation in the lime content. The glacial and other surface clays are very high in lime, so that they all effervesce strongly with acid. This is also true of the Cretaceous clays. These range from 0.65 to 7.91 per cent, with an average of 2.79. The Cretaceous shales have a great variation in lime, ranging from those of the Niobrara formation, which are very calcareous, with as much as 40 per cent. of lime, to some of the Pierre shales, with as low as 0.25 per cent, and of the Benton shales with as low as 0.75 per cent.[2] The Tertiary clays, which are of the higher grades, show great variations in lime. Most of the

[1]N. J. Geol. Survey, Vo.. VI, p. 64.
[2]H. A. Mayo furnishes these figures which are taken from an analysis of the Benton exposed on his property.

samples, however, are low in lime. The limits are from 4.52 per cent. in an impure, sandy clay, to a trace only in one of the best pottery clays. The average is 0.48 per cent.

Lime silicates, as already stated, furnish but a small percentage of lime in clays, and they are thus the least harmful of all the lime minerals. The carbonate, which is the most common, is not specially harmful for the common uses of clay, if it is uniformly distributed, but if it is segregated in concretions or small lumps of limestone, as is frequently the case in glacial and alluvial clays, then it becomes a very troublesome factor. In these large pieces it is most liable to injure the brick in burning. The carbon dioxide (CO_2) is driven off at moderate temperature, leaving behind the oxide or ordinary unslaked lime. Unless the temperature is carried high enough to cause the formation of a lime silicate, the lime remaining will absorb water, after being taken from the kiln, and slake, forming lime hydrate $Ca(OH)_2$. This causes swelling, and if the lime is in large pieces the expansion may be sufficient to badly damage or even ruin the bricks or other ware. When finely divided the lime does not do so much harm, except that it is soluble in water carrying carbon dioxide, and may form an efflorescense on the surface of such ware as brick, which is alternately wet and dry. Another effect of the lime carbonate is to leave the brick very porous. All the common brick clays of North Dakota are high in lime, and the brick are rather porous, unless highly burned, although they show a fair strength test.

When burned to moderate temperatures the lime combines with the silica and very easily forms fusible silicates. These are white and neutralize in part the color given by the iron, so that clays high in lime burn buff, even if they contain considerable iron. Ries states that the bleaching effect is most marked when the percentage of lime is three times that of iron. The formation of the easily fusible silicates also causes the clay to soften rapidly, bringing the points of incipient fusion and viscosity sometimes to within 76 degrees F.[1] of each other. This was very noticeable in testing the North Dakota clays. The bricklets when burned in a muffle sometimes formed a glassy slag on the side next to the muffle bottom, while a fraction of an inch above the bottom the clay would not even show incipient fusion, but could be easily scratched with a knife. This prohibits the use of clays high in lime for vitrified products. Lime as the hydrated sulphate, gypsum ($CaSO_4 2H_2O$),

[1] N. J. Geol. Survey, Vol. VI, p. 61.

is very common in certain of the North Dakota clays, especially the glacial and lake clays and the Pierre clays. Gypsum is white or transparent, and is a very soft mineral. Gypsum occurs interstratified in thin layers with the clays, and also occurs as dispersed crystals, sometimes of considerable size, but usually small, or as evenly distributed grains.

At a low heat the combined water of the gypsum is driven off and plaster of Paris is left finely distributed through the ware, while at a high heat, sulphur trioxide(SO_3) is driven off, leaving behind the lime (CaO), which combines with the silica of the clay to form a fusible lime silicate. The sulphur trioxide is only completely eliminated at quite high temperatures, 2,300 degrees F., or higher. That this temperature is higher than was ordinarily believed was shown by Ries' experiments.[1] These also proved that the clay did not soften so readily by the fluxing action of the lime derived from gypsum as from the same quantity derived from the carbonate. Danger to the ware is sometimes experienced, however, by the clay softening before the sulphur dioxide is entirly driven off, and being imprisoned by the dense, softening clay, expands it and makes it porous and often bleaches it. Gypsum left in low burned wares as calcined gypsum or plaster of Paris, often causes a slight efflorescence on surfaces alternately wet and dry.

Magnesia.—Magnesia is a substance which is similar in its properties to lime. It is by no means such a powerful flux as lime, and usually occurs in small quantities in clay. Ries[2] gives the following table showing the amount of magnesia in several clays:

	Minimum.	Maximum.	Average.
Brick clays	0.02	7.29	1.052
Pottery clays	0.05	4.80	0.85
Fire clays	0.02	6.25	0.513
Kaolins	trace	2.42	0.223

The amount in the North Dakota clays is generally low. One calcareous clay from the Tertiary horizon shows the high percentage of 4.22. This material has an extremely high air shrinkage, 19.0 per cent, and requires some 61.8 per cent of tempering water. Some of the clays of the coal measures show a variation of from 0.50 to 3.84 per cent, with an average of 2.03 per cent. The Benton shales have somewhat above the average, about 1.5 per cent. The Tertiary clays as a rule are very low, ranging from a trace to 4.22 per cent, with an average of 0.74 per cent.

[1]N. J. Geol. Survey, Vol. VI, p. 63.
[2]Ibid., p. 67.

Magnesia occurs in most cases as part of a decomposition product from the dark colored silicate minerals, such as biotite and hornblende. It also occurs as magnesian limestone. Sulphate of magnesia, Epsom salts, are also found to some extent, and can be readily detected by their bitter taste and their solubility. Ries,[1] quoting a German experimenter, Mackler, states that magnesia, although a flux, is different in action from lime. It causes the clay to soften more slowly, so that the points of fusion and viscosity are separated much more than in limey clays; also the bleaching action of the magnesia on the iron is not so strong.

Alkalies.—The common alkalies present in clay are potash (K_2O) and soda (Na_2O). These are derived from the alkaline silicates, and in North Dakota not infrequently from alkaline carbonates which have been formed by long continued burning of prairie grass and the slow seepage of the soluble carbonates into the clay deposits. Feldspars and light colored micas are present in all clays, ranging from a trace up to 10 per cent or more. Ries gives the following amounts as present in different kinds of clay:[2]

	Minimum.	Maximum.	Average.
Brick clays	0.17	15.32	2.768
Pottery clays	0.52	7.11	1.46
Fire clays	0.048	5.27	2.06
Kaolins	0.1	6.21	2.768

Only a portion of the North Dakota clays mentioned in this report have been analyzed for alkalies, those that have been showing a small amount. The clays selected had a high melting point. They range from 0.32 to 3.22 per cent, with an average of 1.32 per cent. The Laramie clays as a rule show somewhat higher values, all those analyzed ranging from 0.47 to 2.00 per cent, the average of five analyses being 1.08 per cent.

The alkalies are the most important fluxing agents and determine very largely the melting point of a clay unless very high in the other fluxes. They are different in their action from lime, in that they cause the clay to soften at a lower temperature, but to melt very slowly, so that the range between the temperatures of incipient fusion and viscosity is broad. This makes the alkalies desirable constituents of clays for vitrified ware, the clay burning to a very dense, hard body. The allowable percentage in fire clays is small, and depends on the texture of the clay, but it should not exceed 1.5 to 2 per cent. Most of the best fire clays show much less than that amount; not much, if any, over 1 per cent.

[1] Ibid., p. 65.
[2] Bull, 35 N. Y. State Museum, p. 515.

Titanium.—Titanium is an element which is quite common as an impurity in clay. Its determination is rather a long and difficult one and is seldom carried out, the titanium oxide (TiO_2) being weighed with the silica and the alumina. It resembles silica in its effect on the properties of clay, but is a stronger flux at high temperatures, so that its determination may be of importance in very refractory fire clay products.

It occurs in clays as the oxide mineral, rutile, which is of common occurrence as small grains in acid igneous rocks, and as it resists weathering, is found in the resulting clays. The percentage found in most clays is very small, seldom reaching 1 per cent, which amount has little effect on the material. The amount in the North Dakota clays was not determined, but there is nothing to lead us to think it is present in these clays in more than traces.

Manganese.—Manganese does not occur in most clays in any appreciable quantity. The oxide pyrolusite is, however, probably present to some extent. It is similar to iron in its properties, and is often added to pressed brick clays to give them a dark brown or black color.

Manganese is a very important and much used element in the manufacture of wares which demand definite and pronounced colors and tints. Where wine colored to reddish tints are desired, manganese free from iron is used with a white burning clay. Brown to black tints are secured by using a mixture of manganese and iron oxide, the proportion being varied with the depth of color desired.

It will be seen that, by starting with a pure, white burning clay, such as is found in several localities in North Dakota, a great variety of colors can be secured, ranging from a pink or wine color to dark brown or nearly black.

Water.—Water occurs in clay in two forms, as mechanically included water or hygroscopic moisture, and as chemically combined water. The first form consists of the water which exists in the pores of the clay, and surrounding the individual grains. The amount present depends principally upon the texture of the clay. Fine grained clays naturally hold more water in their pores, by capillary attraction, than coarse grained ones. Most of this mechanically held water is eliminated by air drying at ordinary temperatures. Clay as it occurs in the bank may contain 20 to 40 per cent of moisture. To this water the plasticity of the clay is largely due, but ordinarily more water has to be added in

order to develop its maximum plasticity. The total amount of water of plasticity varies from 20 to 40 per cent, some sandy ones requiring only about 15 per cent, while some very fine grained ones take 50 per cent or more. The limits of the tempering water of the North Dakota clays tested was from 15.3 per cent to 61.81 per cent, most of them requiring between 20 and 30 per cent, the average being about 25. This amount varies greatly in actual operations with the products to be secured and the processes employed.

The water not expelled by air drying is only driven off at the temperature of boiling water, 212 degrees F. (100 degrees C.) The loss of mechanically combined water is accompanied by a corresponding shrinkage, the amount being roughly proportional to the amount of water driven off. The shrinkage varies from 1 per cent in sandy clays up to 10 or 12 per cent in fat ones, the clay with the extremely high absorption noted above showed an air shrinkage of 19.0 per cent. Most of the clays have an air shrinkage of between 3 and 6 per cent. The elimination of the water must not be carried on too rapidly, else the surface of the ware will become dry before the interior has had a chance to dry much, and the corresponding shrinkage of the surface will cause the ware to crack or check.

This water in drying may also dissolve the soluble salts, if any exist in the clay, and bring them to the surface of the ware, where they are deposited when the water has evaporated. This is called scumming or white washing.

Chemically combined water is an essential part of kaolinite and other hydrous minerals such as limonite and mica. In pure kaolinite there is 13.9 per cent, but this amount is rarely present in clay. Wheeler[1] gives the usual range as from 5 to 12 per cent, and the average about 8 to 10 per cent. Ries[2] says unless the clay contains considerable limonite or hydrous silica, the percentage of combined water is commonly about one-third the percentage of alumina found in the clay. The combined water has a very marked effect upon the plasticity and fire shrinkage, in some cases determining the possibility of the use of a clay for certain purposes. This combined water is driven off at a red heat, and only entirely eliminated at from 600 degrees C. (1,112 degrees F.) to 1,000 degrees C. (1,838 degrees F.)[3] This is accompanied by a further shrinkage and a loss of the property of plasticity.

[1] Mo. Geol. Survey, Vol. XI, p. 58.
[2] N. J. Geol. Survey, Vol. VI, p. 73.
[3] West Va. Geol. Survey, Vol. III, p. 20, Grimsley.

Organic Matter.—More or less organic matter is usually present. In surface clays it consists of decaying roots and other vegetation. In stratified clays, fine carbonaceous particles are often deposited along with the clay. The carbonaceous material may be distributed in layers, giving a banded appearance to the clay. Some of these layers are of appreciable thickness, and become more highly carbonized by distilling off some of the light gasses under pressure, and out of contact with the air, forming thin lignitic seams. These lignitic layers and patches are very common in the North Dakota clays. They are usually fossiliferous and show the imprints of the leaves and bark which were buried in the clay.

The amount of carbonaceous material is usually not very great, 1 to 4 or 5 per cent, but sometimes it is considerable. Some of the clays associated with lignite are high in carbonaceous matter, as shown by their high loss in ignition, much higher than could be accounted for by loss of combined water and sulphur. One clay showed a loss as high as 21.82 per cent.

The effect of the carbonaceous material is to color the raw clay, giving it a blue-gray, black or sometimes brown color. If in any quantity and distributed through the clay it clouds the color imparted by iron oxide or other coloring agents, and generally obscures the nature of the clay. It also acts as a reducing agent and keeps the iron in the ferrous form. Carbonaceous matter does not ordinarily effect the color of the burned clay, as it is burned out at a low red heat. All the carbon must be oxidized, however, before the iron or other substances can be. It is, therefore, necessary that it be completely burned out at a low temperature, so that no iron shall remain as ferrous oxide which at more elevated temperatures tends to slag and darken the ware. If the clay is burned to semifusion before the carbon is entirely expelled, the imprisoned carbon dioxide will warp and bloat the clay. If the carbon is present in quantity, it will, with free draft, increase the temperature of the kiln when burning, and allowance must be made for the increase. But if burned with a limited supply of air and with a low, smoky fire, the reverse will be the effect, and the burned products will be greatly effected in color, hardness and in other properties. If the carbonaceous material is in larger lumps or fragments, the clay is left porous after burning it out. But it is ordinarily finely distributed, and with careful burning all its harmful effects may be readily overcome. A large proportion of the clays outside of the Red River Valley bear traces of powdered lignite.

Soluble Salts.—It has been explained above that if the clay contains any salts which are soluble in water, these are dissolved by the tempering water, and on drying, especially on rapid drying, are carried to the surface of the ware, where on the evaporation of the water they are deposited as a white scum or "white wash." These soluble salts are usually sulphates of lime, magnesia, iron and the alkalies. They are formed by the decomposition of the minerals of the clay, especially those which contain pyrite. Sulphates and carbonates may in some cases be formed by the action of the hot gases in the kiln, especially during the first stages of burning. Soluble salts are introduced to a certain extent by the tempering water, which always contains some soluble substances. This is a matter of great importance in the manufacture of the finer clays into higher grades of pottery.

The quantity of these salts is usually small, varying from a trace to something over one per cent, but usually averaging considerably less than a half of one per cent in the better grade of clays. Ries[1] states that less than 0.1 per cent is often sufficient to produce a white incrustation. This does not always form on the brick during drying or in the kiln, especially when the clay is dense, but is more likely to be brought to the surface after the brick has been exposed to the weather some time.

The best method of preventing the formation of white washes is to change the soluble salts into insoluble ones. This is done by adding barium carbonate ($BaCO_3$) or barium chloride ($BaCl_2$) to the clay, which react with the soluble sulphates to form barium sulphate ($BaSO_4$), the latter being insoluble in water. The chloride can be added as a solution, the carbonate only as a fine powder held in suspension. Ries[2] calculates that a clay with one per cent of lime sulphate would require about 100 pounds of barium carbonate for every 1,000 brick, at a cost of $2.50, while only twenty-six pounds of barium chloride would be needed, the cost being only $.065. With the barium chloride, care must be taken not to use too much, as it is itself soluble and might form an incrustation.

It will appear from what has been said regarding the composition of clays that there is an almost endless variety and that different clays blend gradually in their composition and uses. It is therefore almost impossible to draw narrow limits for their classification according to their uses.

[1] N. J. Geol. Survey, Vol. VI, p. 76.
[2] Ibid, p. 79.

Clays are of such complex composition that the reaction of all the different constituents must be calculated and the final result taken into consideration before determining the use for which a certain one is adapted, and they vary so greatly in their physical characteristics as well as their chemical composition that it is extremely difficult to group them into narrow classes. In arriving at any such classification the methods required in working them and the uses to which they are to be put must be given careful consideration. The chemical analysis alone can not be relied upon in arriving at these conclusions, for the physical properties play an important part and determine in a considerable measure the peculiar character of the product. The usefulness of a clay for a given purpose often depends in no small degree upon the plasticity, the shrinkage or the color imparted at certain temperatures. An estimate of a clay must therefore be a summary of the chemical and physical properties when all are carefully blended.

CHAPTER III.

THE PHYSICAL PROPERTIES OF CLAY.

BY C. H. CLAPP.

The Physical Properties of Clay.—The value of a clay is determined by its physical as well as by its chemical properties. The physical properties are more or less dependent upon the chemical composition, especially such properties as color and fusibility, but the chemical analysis does not show many features which determine the value of the clay and the uses to which it may be put. These qualities, such as texture, plasticity and shrinkage are of great importance. They are best determined by actual tests with full sized ware and with large quantities of clay, but may also be quite accurately found out by laboratory tests. For the best estimation of the value of the clay, the chemical analyses and physical tests should supplement one another.

The following physical properties of only the raw and burnt clays will be discussed: Structure, hardness, texture, porosity, specific gravity, homogeneity, odor, taste, feel, color, slaking, plasticity, strength, shrinkage (both in air and fire) and fusibility.

Structure.—Clay is ordinarily composed of fine grains, arranged in no particular way, and compacted into a hard or soft, structureless or massive body, with an earthy appearance. By consolidation after deposition, mainly by pressure, subsequent structures are produced. The clay may become so altered, or metamorphosed, that it is turned to slate with a slaty cleavage. In such cases it loses its clay properties. It may retain its value as clay, though changed to a shale, with a shaly structure and breaking easily into plates parallel to the bedding planes. This separation may be due largely to a change in the character of the component grains; if this is marked, as from fine to coarse grain, or from a blue to brown color, it gives to the clay a laminated structure. As a clay hardens it develops joints, mainly by shrinkage, but also, after induration, by pressure and tension. Clays containing a soluble constituent, such as limonite, which may, by precipitation from the solution, collect in concentric layers around a nucleus, are often concretionary.

The structure of a clay effects its value in that it influences the method of mining employed. Advantage is taken of the jointed and shaly structure in blasting or undermining. Soft, massive clays may be dug by a steam shovel or by hand. Concretionary clays should be crushed or screened. The structure, therefore, largely determines the method of mining.

Hardness.—Clay is generally soft and easily scratched with the finger nail, the hardness depending on its chemical composition, moisture and compactness. Ordinary clay with a fair amount of kaolinite cannot exceed the hardness of that mineral, which is a little over 2. Indurated clays, especially those high in quartz sand, may attain a much greater hardness so that they cannot be scratched with the finger nail, but are scratched readily by steel, the maximum hardness being about 3.5. The chief effect of hardness is on the ease of working; that is, crushing and tempering. Clay is made harder by burning, becoming steel hard at incipient fusion, and obtaining the hardness of quartz at vitrification. This change is more fully discussed under fusibility.

Texture.—The texture, or fineness of grain, of clay is an important factor in determining the other properties. It influences plasticity, shrinkage, porosity and fusibility. The grains of pure clay or kaolinite are very fine—finer than can be seen with the eye or felt by the hand or between the teeth. The grains of the mineral impurities, such as feldspar, mica and quartz are often of appreciable size. The actual size and the percentage of these coarser particles is of great importance; and in a complete analysis great pains is taken to determine the relative sizes of the grains and the percentage of each size present.

For rough work much can be told of the fineness of grain by slaking and feel, and by testing the clay between the teeth. This was the method employed in testing the clays described in this report, since lack of time prevented any fuller tests. For practical purposes, Ries[1] states that it is perhaps sufficient to determine the per cent of any sample that can be washed through a 100 or 150 mesh sieve, since in preparation of clays for the market, they are not required to pass through any sieve finer than that. Wheeler[2] suggests for rough determinations the dropping of a piece of perfectly dry clay into a glass of clear water. The clay more or less rapidly falls into a conical pile of particles (slakes), that vary in

[1]N. J. Geol. Survey, Vol. VI, p. 107.
[2]Mo. Geol. Survey, Vol. XI, p. 92.

size from one-quarter to one-twentieth of an inch in coarse clays, one-twentieth to one-fortieth of an inch in medium clays, and one-fortieth to one-two-hundredth of an inch in fine clays. This method of testing does not seem to be of much value, as it does not give the proportion of fine and coarse material, and results as accurate and of greater value can be obtained by feel.

More accurate sizing must be done by one of the more improved methods. The clay must first be entirely disintegrated by boiling or stirring and then it may be sized or classified in various ways. One method is by allowing the clay, after being stirred up with water, to settle a certain length of time, and then decant off the liquid and the particles in suspension and allow it to stand a longer period of time, and so on. The sizing may be done in upward moving currents of water, of different velocities, similar to the classifier used in ore sizing. The best way is by the centrifugal method, which is employed by the Bureau of Soils of the United States Department of Agriculture[1] in analyzing soils. This consists in revolving very rapidly the clay held in suspension. By employing different rates of speed and by revolving the clay varying lengths of time, the sizing is most accurate.

The following nomenclature is used in describing the sizes of grain.[2] Table showing size of grains of sand, silt and clay:

	Size of Diameters. Inches.	Millimeters.
1. Gravel	1-12— 1-25	2—1
2. Coarse sand	1-25— 1-50	1—0.5
3. Medium sand	1-50— 1-000	0.5—0.25
4. Fine sand	1-000— 1-250	0.25—0.1
5. Very fine sand	1-250— 1-500	0.1—0.05
6. Silt	1-500— 1-2500	0.05—0.01
7. Fine silt	1-2500— 1-5000	0.01—0.005
8. Clay	1-5000—1-25000	0.005—0.0001

A clay usually shows great variety in texture, the size of the grains varying from fine clay to coarse sand, or even gravel. The white, sandy clays of North Dakota consist of a rather coarse, pure quartz sand, the grains of which are coated over with a very fine pure kaolin.

The texture has a marked effect on the plasticity of the clay. Ordinarily, other things being equal, the finer grained the clay the more plastic. However, the plasticity is not due entirely to the fineness of the particles, but rather to their shape and structure, so

[1]For description see Bull, 24 Bureau of Soils, U. S. Dept. of Agriculture, Wash., D. C.

[2]Ries, N. J. Geol. Survey, Vol. VI, p. 108.

that mere fineness is not always an indication of plasticity. It is even possible for a clay to be too fine grained, as is illustrated by the fact that it can be overworked in the pug mill, the scale-like structure of the particles being broken up, so that the clay becomes dead.

The shrinkage is usually greater the finer the clay. The porosity, the rapidity of drying, and to some degree the rapidity of burning, is also determined somewhat by the texture. There are, however, many exceptions to these general statements, those factors being also dependent probably on the range of sizes, and the shape of the clay grains.

The size of grain has a very important influence on fusibility, and this will be discussed under that head. Under the same condition, the finer grained the clay the more fusible it becomes. Coarse, sandy clays, sometimes with a very large percentage of fluxes, may retain their shape at very high temperatures. Manufacturers of refractory wares take advantage of this fact, and do not crush the clay and grog fine.

Porosity. The porosity of clay is due to the irregularity of its grains. It has been shown that these vary greatly in diameter, and the same is true as regards their shape. It is manifestly impossible for these grains to fit together so as to be non-porous. The maximum porosity, which is the ratio of the volume of the open or pore spare to the volume of the clay, would be developed if the grains were round and all of the same size. This condition is, of course, never reached, the porosity varying as the shape and size of the component grains.

Its porosity seems to affect the properties of the clay but little, and the size and character of the pores have more influence on these properties. Two clays, a coarse one and very fine one, may possess the same porosity, yet their properties will be entirely different. The coarse clay will absorb water readily, and will require less tempering water than the fine clay. The shrinkage is, however, very probably dependent to a great extent upon the porosity, the power of the clay to shrink to the smallest volume, and the small grains becoming packed in between the large ones. The rapidity of drying is possibly somewhat dependent on the porosity, but more on the size of the pores. The clay in which the pore spaces have the larger diameter is evidently capable of being dried the faster.

The determination of the porosity of raw clays is therefore believed to be of little value, whatever effect it may have on the shrinkage for instance being more easily found out by the actual

shrinkage test. For this reason no porosity tests were made on the North Dakota clays.

The porosity of the burned ware, or its absorption power is, however, of more importance. It is to a great extent a measure of the vitrification of the ware. Specifications for paving brick, for example, usually call for brick with an absorption of not over 3 or 3½ per cent. The wearing, or rather weathering qualities of a brick is also dependent upon the porosity. A porous brick absorbs water, and this if frozen expands and tends to crack the brick. But here again the size of the pores plays the more important part, since in the coarse textured brick the water has a chance to expand and therefore exerts no strain, while in the fine grained one it does not have this opportunity and is apt to rupture the brick.

The porosity of the burned ware is best determined by finding the volume of water absorbed by a known volume of burned clay. It is, however, usually obtained as the percentage absorption by weight. The burned clay is weighed and then immersed in water for a definite length of time, usually 48 hours, although for complete saturation the time should undoubtedly be much longer, and then taken out and reweighed. The difference in weight, divided by the weight of the dried ware, gives the percentage absorption. This depends upon the texture and porosity of the raw clay, the temperature of burning, the fusibility and shrinkage of the clay, and varies all the way from 30 to 35 per cent. in sandy clays burned at low temperatures, to almost zero in clays which have been vitrified.

Specific Gravity. The true specific gravity of a clay, the number of times heavier it is than an equal amount of water, as defined by the more recent writers on the subject, is dependent entirely upon the mineral composition of the clay. It is found by testing the clay in a pycnometer. The specific gravity of kaolin is about 2.6; the common impurities, quartz and feldspar, range from 2.55 to 2.75, while some of the others, notably the zeolites, are lighter, and the iron minerals are considerably heavier.

The apparent specific gravity, which is the weight of the raw clay, compared to the weight of an equal volume of water, takes into consideration not only the mineral constituents, but also the porosity and amount of moisture present and therefore depends on the composition and degree of consolidation.

Grimsley[1] has tabulated the specific gravities of clays from different states from the various state reports, with the following result:

[1]West Va. Geol. Survey, Vol. III, p. 65.

Georgia clays (apparent specific gravity)	1 to 2.5
Missouri clays (apparent specific gravity)	1.09 to 2.56
New Jersey clays (apparent specific gravity)	1.52 to 2.32
New Jersey clays (true specific gravity)	2.34 to 2.84
Iowa clays (true specific gravity)	2.32 to 2.64
North Carolina clays (true specific gravity)	2.24 to 2.68
West Virginia clays (apparent specific gravity)	1.68 to 1.84
West Virginia clays (true specific gravity)	2.34 to 2.68

The influence of the true specific gravity on the properties of the clay is not of much importance in itself, it is merely dependent on the chemical composition. The apparent specific gravity is supposed to influence the fusibility, but on this question the different authors on the subject do not agree. Wheeler[1] states that the denser the clay the greater the refractoriness. Buckley[2] in his report on the Wisconsin clays doubts this conclusion, while Beyer and Williams[3] assert that the more compact and more porous the clay, other things being equal, the higher the specific gravity and the lower the fusion point. The writer is inclined to favor the latter view. The specific gravity determinations, either apparent or true, were not considered of sufficient importance to make them worth while. The effect on the fusibility is doubtful, and in any case is not of great importance.

Homogeneity. The homogeneity of clay is a very important factor, especially in the production of the finer grades of ware. As they occur in the bank, clays are rarely very uniform, containing concretions, laminations, and varieties in texture. This lack of uniformity causes checking and cracking, due to irregularities in shrinkage and expansion, and gradations in the color. The presence of lime particles and mica scales is apt to cause mottling and slagging of the ware. Thus it becomes very necessary that the clay be ground and thoroughly mixed before going to the moulding machinery. The homogeneity can best be determined by inspection of the clay in the bank, in the sample by a lens and under the microscope, and by studying the effects of the different tests with regard to it.

Odor. Most clays have a characteristic earthy, clayey or argillaceous odor, especially when damp. This is supposed by some to be caused by ammonia or other volatile matter, for the burned clays have no such smell. It is popularily considered a test of the purity of the clay, but it is of no value whatever, some of the very best clays having no such odor, particularly the flint clays.

[1]Mo. Geol. Survey, Vol. XI, p. 91.
[2]Wis. Geol. Survey, Bull, Part I, p. 19.
[3]Iowa Geol. Survey, Vol. XIV, p. 114.

Taste. Sometimes the presence of soluble salts, such as alum, epsom salts and sulphate of iron, can be detected by the taste of the clay. Some idea of the texture of the clay can be obtained by grinding the clay between the teeth. It is nothing but a field test and is of no great reliability.

Feel. Clays have a more or less soft, greasy or soapy feel when rubbed between the fingers. Sand grains can be felt, and if somewhat wet, as it usually is in the bank, some idea of the plasticity can be obtained by crushing it in the hand. The method is a rough field test, but with experience is of some value in determining the plasticity and texture of a clay.

Color. The color of kaolinite is white, therefore the color of pure clays consisting only of kaolin and quartz is likewise white. Few clays, however, are free from impurities, and these impart certain colors to the raw material. The common coloring agents are the compounds of iron and organic matter. Ferrous compounds, notably pyrite and siderite, color the clay gray or greenish; the ferric compounds, limonite and hematite give colors ranging from yellow to red and even brown. Carbonaceous matter imparts a gray, or black, and rarely a brown color.

The color of the raw clay furnishes but little information as to the color to which the clay will burn or its purity. If entirely free from carbonaceous matter, the color of the clay may be taken as indicative of the amount of iron present. Yet even in this case sandy clays, and some others, are more intensely colored by the same amount of iron than finer clays. The nature of the iron and the minerals in which it occurs, of course greatly influence the color. If carbonaceous matter is present, the true nature of the clay is entirely obscured and it is impossible to tell to what color it will burn.

The colors of the burned product are of more brilliant and clearer shades than those of the raw clay. They are due almost entirely to the iron oxides, the colors given to the raw clay by carbonaceous matter being destroyed as the carbon is burned off at a low temperature. The color varies with the amount of iron, the presence of other elements, and the conditions under which the clay is burned.[1] Pure kaolin, with little or no iron, manganese or lime, burns white. Some refractory clays containing titanium burn blue, while others with small amounts of iron burn buff and yellow to brownish. Clays of lower fusibility and larger amounts of iron burn pinkish or salmon colored to red in an oxidizing atmosphere, and

[1] Wheeler, Mo. Geol. Survey, Vol. XI, p. 83.

greenish or black in a reducing atmosphere. When brought to vitrification the colors are dark brown or black, and sometimes greenish. If the clay is not homogeneous, the burned ware will be mottled. The presence of large amounts of lime and alumina neutralizes the colors imparted by iron and gives the burned product yellow and buff shades.

Slaking. When an air-dried lump of clay is completely immersed in water it swells up and falls into flakes and small particles, or slakes. The rapidity and completeness with which this slaking takes place varies greatly with the kind of clay. Hard, indurated shales and flint clays sometimes require several days or weeks, and even then may not be completely slaked. Other hard clays, such as some of those of the coal measures, take only "two to ten minutes for an inch cube to pass into a cone of fine powder."[1] The surficial and unconsolidated sedimentary clays usually slake quickly, especially the sandy ones. Some of the shales, even the soft ones like those found in North Dakota, break up quickly into thin flakes and scales, but are not completely broken up until they have been ground.

The rapidity of slaking is found out by noting the time it takes a lump of air-dried clay, approximately an inch in diameter, to crumble down in water. This varies from one or two minutes in lean, sandy clays, to a couple of hours in unconsolidated, fine, plastic clays, to several weeks in hard shales. Beyer[2] states that as regards shales, those which slake most readily are the finer grained and stronger. All the North Dakota clays slake rapidly, within three hours, and most of them within an hour, except one or two of the Benton and Pierre shales, which break up into flakes.

The determination of the slaking power is not of much value in ordinary soft clays, but it is of value in indurated clays and shales. The more easily a clay slakes the more easily is it tempered. The property is of especial importance in the washing and weathering of a clay, where it is necessary for the best results, that the material should disintegrate easily in water.

Plasticity. Plasticity is that property of clay, developed when wet with water, of being moulded or pressed into any shape desired and retaining that shape on drying. The degree of plasticity varies widely from that found in lean clays to that exhibited by fat clays which are most plastic. Lean clays are usually sandy and coarse while the fat are commonly fine-grained, but this does not

[1]This has been more fully discussed under iron in chapter II.
[2]Iowa Geol. Survey, Vol. XIV, p. 78.

always hold true, many factors affecting this property. It is the most important property, since it is the one which gives the clay the power to be fashioned into the shapes in which it is subsequently used.

Many theories have been advanced as to the cause of plasticity, some of them of little value, others furnishing more plausible explanations. Many authorities today do not attempt to explain the cause of plasticity by any one property or condition of the clay, but rather by a combination of several factors, which are of a physical rather than chemical nature.

The theories advanced up to 1895 have been admirably discussed by Wheeler in his report on the Missouri clays and will be briefly reviewed. One of the oldest of these theories held that the combined water of the kaolinite was the cause of plasticity because when this water is expelled at red heat the clay is rendered non-plastic, and even by fine grinding the former plasticity cannot be renewed. But many minerals which contain combined water and are of a similar composition to kaolinite do not possess plasticity. Also, clays which are the most plastic are not necessarily the highest in combined water, and sometimes those which are very high in combined water, and have a composition approaching that of pure kaolinite, such as the flint fire clays, are very lean. The change which takes place at red heat, besides driving off the water, also affects the physical structure and properties. and so may well affect the plasticity.

The impurity theory was based on the supposition that pure kaolins are not plastic, and that impure clays are, due to the presence of certain impurities which acted as flexible binders to the kaolinite particles. The theory can not be held, as the supposition is far from being true. many pure kaolins being plastic, and some of the non-plastic ones becoming so on weathering. Also the addition of the common impurities included under the term sand, decreases the plasticity.

That clays are plastic because of the alumina they contain is untenable, because some clays high in alumina are not plastic, and others which are low in alumina are plastic.

The so-called interlocking theory is based on the fact that some clays seem to contain, under ths microscope, certain curved and hook shaped crystals, which by interlocking allow the particles considerable freedem of movement, yet hold them together, giving the clay its necessary strength to retain the moulded form. How-

ever, even in the clays examined by the supporters of this theory, the crystals were not abundant, and in many plastic clays are entirely absent.

It is well known that the majority of clays are rendered more plastic by fine grinding. Based on this fact, another theory has been long held, that the plasticity of clays is due to the fineness of the clay particles. But plasticity can not be due solely to fineness, as non-plastic flint clays, or other minerals such as quartz or feldspar, do not become truly plastic even when very finely ground. They seem to be plastic when wet, due to the adhesive power of the water surrounding the grains, but on drying have little or no strength. Also if a clay has been ground too finely and worked up too long, it loses some of its plasticity and is said to become dead. Again in testing clays it has been shown that those passing through 20 to 100 mesh screens are more plastic than those which are finer. Therefore, fineness although affecting plasticity cannot be the sole reason for that important property.

G. H. Cook of New Jersey first advanced the theory which, as modified in the light of more recent investigation, is held most generally today. By microscopic examination he noticed in clay thin, plate shaped particles and believed that they were the cause of plasticity. The idea was developed by several other experimenters. Wheeler, in particular, after the examination of the Missouri clays, arrives at the conclusion that the fine plate theory most satisfactorily explains plasticity.

He substantiated his conclusion by the following arguments: Clays seem to be made up of thin plates, which in non-plastic clays occur in coarse bundles, and in the more plastic ones are more or less separated, the finer and more numerous the plates, the greater the plasticity. Plastic clays are improved by fine grinding and weathering. Weathering in all cases, as shown by a very careful series of experiments performed by F. F. Grant on the West Virginia clays,[1] improves the plasticity of clay, and as it does not affect the chemical character it must be the physical character. Wheeler accounts for the change by the breaking up of the coarse bundles into separate scales, a process which seems to be substantiated by the microscope. Ries[2] notes a case where a residual clay of essentially the same composition as a transported clay, possessed a decidedly less degree of plasticity, the particles of the latter probably being broken up during the transportation. Again, certain min-

[1]West Va. Geol. Survey, Vol. III, p. 47.
[2]N. J. Geol. Survey, Vol. VI, p. 82.

erals with a lamellar structure, such as gypsum, calcite and slate, develop plasticity when finely ground. Plastic clays must ordinarily be dried very carefully, but once dried may be burned rapidly, exactly the reverse being true of non-plastic clays. Wheeler accounts for this by supposing that the water of plasticity is tightly held by the interlocking grains, and as suggested more recently, by the attraction between the clay particles and the water. The dried clay can be heated quickly as the interlocking grains and their attraction for one another give the clay sufficient strength to withstand the strain produced by rapid burning.

Objections to this theory are that many clays do not appear to be made up entirely of plates.[1] Most of the writers on the subject hold that the theory while being correct in principle does not explain all the facts and is not broad enough to include certain other principles and properties which undoubtedly affect the plasticity of a clay.

Ladd[2] holds that the water of plasticity, by reason of the attraction between the water and clay particles, and by the surface tension of the water films, acts as a lubricant and a binder, and thus influences the plasticity. In much the same way, as has been suggested by Ries[3] and Cushman,[4] colloids, which are amorphous, glue-like or jelly-like substances, affect the plasticity. These colloids, which may be hydrated silicic acid, metallic hydroxide, or of organic origin, are supposed to exist as small, spherical, structureless particles which are seen in clays under the microscope. Grout,[5] after a very careful study of the action of colloids, states that only those which will soften in water after air drying and are of organic origin, and also some crystalloids like gypsum and alum, are effective. Grout himself arrives at the conclusion that the molecular attraction between the shell of water surrounding each grain of clay is the chief or fundamental cause of plasticity. The cohesion or bonding power thus developed allows the particles to move without rupture, and also offers a certain amount of resistance to movement, plasticity being defined by him as depending on these two factors. The greater the molecular attraction, the thicker the shell of water surrounding the individual grains will be, and consequently the plasticity will be proportionately increased. The attraction depends on the chemical constituents of the molecule.

[1]Ries N. J. Geol. Survey, Vol. VI, p. 82.
[2]Geol. Survey of Georgia, Bull, No. 6, p. 31.
[3]Maryland Geol. Survey, Vol. IV, p. 251.
[4]Journal Amer. Cham. Soc. XXV, 1903.
[5]West Va. Geol. Survey Vol. III, pp. 48 and 49.

The theory has many ingenious points, and explains the action of the fineness of grain, thin plates, and colloids.

Undoubtedly all these factors have their influence on plasticity, but one should be careful not to place too much emphasis on any single one.

Many methods have been devised of determining the plasticity of clay. There is evidently need of one by which the results of different experimenters may be compared. Such a one is, however, mainly of scientific interest. Bishof has suggested forcing wet clay through a die into narrow cylinders, and measuring the length of the columns before breaking by their weight. The tensile strength of dried and wet clay has also been tried.

Grout's[1] method consists in measuring (1) "the amount of possible flow before rupture" by compressing wet clay cylinders with different percentages of tempering water until they fail by cracking and recording the amount of compression; and to determine (2) "the resistance of flow of deformation" by noticing the weight required to force a Vicat needle (a needle used in testing the set of cement) of one-eighth of an inch in diamter three centimeters into the clay in half a minute. From the data thus obtained curves are plotted, these being combined to give the curve of plasticity, which is the product of the two factors. The highest point in the curve shows the maximum plasticity and the abscissa of the point gives the tempering water required for that plasticity. This appears to be the best method yet devised, but, it has not been tested fully.

The rough determination of plasticity by working a little of the clay in the hands with varying proportions of tempering water is much the simplest and is as good a practical test as any. This is best done by moulding and modelling the clay into different forms, by pressing it into different shaps with a press and noting its action, and comparing the results with the shrinkage and tensile strength of the dried clay. This is of course subject to the personal equation of the experimenter, but good rough practical results are obtainable. This method was used in carrying on the tests for this report. The percentage of tempering water required for the maximum plasticity was obtained by weighing the wet clay, drying in air for a couple of hours at 212 degrees Fahrenheit and weighing. The difference in weights divided by the weight of the dry clay giving the percentage of water. The plasticity is reported as being very good, good, moderate, fair, lean, or very lean.

[1] W. Va. Geol. Survey, Vol. III, p. 41.

Strength—Raw Clay. It is important to determine the strength of the raw clay, as it shows its ability to stand the shocks of handling the unburned ware and the strains of drying. It is also a measure of its bonding power, which determines the amount of grog that can be used. It is also supposed to bear some relation to plasticity, but this relation is not well understood. In general the more plastic a clay the higher will be its tensile strength. This general rule is subject to so very many exceptions that it is of little or no value.

The strength is usually determined as the tensile strength, and is obtained by pulling apart briquettes similar to those used in determining the tensile strength of cement. These briquettes are moulded in brass moulds of definite shape, 3 inches long by 1 11-16 inches wide at the ends, tapering to 1 inch at the center and 1 inch in thickness. The cross section of the center of the briquette is therefore just one square inch. These are broken in a testing machine, the Fairbanks type being the most common. The two ends of the briquette are held in a pair of brass clips and tension is gradually applied until the briquette breaks, the breaking load being recorded.

The clay briquettes are moulded by grinding the clay through a 40 mesh screen and tempering with water to its maximum plasticity, or if the clay is to be used for a definite purpose, the same as would be used on the large scale. A little more than enough to fill the mould is worked up between the fingers and squeezed roughly into shape. It is then forced into the mould, not pounded, and the excess of clay scraped off by means of a spatula or knife blade and drawn to a smooth surface. The moulds are first coated with a thin film of oil to facilitate removal, and are filled on a heavy glass plate also covered with oil. As soon as the briquettes are sufficiently dry, they are taken from the moulds and stood on edge, so that the air can circulate around them freely. To secure an even more uniform drying, they should be turned every once in a while. Drying takes from one to five days, depending on the character of the clay and the temperature and condition of the ware. After complete air drying, the briquette should be placed in a hot air bath at about 212 degrees F., or a little more, for a couple of hours to drive off the last trace of moisture. The cross section of each briquette is then measured and the shrinkage in drying recorded. It is next put into the machine and broken. Care should be taken that the strain is evenly distributed so as to facilitate the rupture

of the test piece at the center. Very often, however, the briquette breaks across the end, but unless due to some imperfection, no matter where the briquette breaks it is safe to assume that the calculated tensile strength is the same as if it breaks at the center. The tensile strength should be calculated, allowance being made for the shrinkage, so as to give the strength in pounds per square inch.

In order that the briquettes shall be as uniform as possible, they should all be made by one person, and with the greatest care. Even then it is difficult to keep the variation in the strength of various briquettes of one sample within 20 per cent, especially with the very strong plastic clays. In order to make the tests as valuable as possible and to allow for this variation, at least ten or twelve briquettes should be broken. The tests made on the North Dakota clays being necessarily of a preliminary nature, only two to six briquettes were made and broken from each sample.

Ries[1] gives the range of tensile strength in clays as follows:

	Minimum.	Maximum.
Kaolins	20 pounds	60 pounds
Fire clays	0 (Flint clays)	150 pounds
Brick clays	50 pounds	300 pounds
Pottery clays	50 pounds	250 pounds

The clays of North Dakota show the usual range, 339 pounds being the maximum. The surface clays which are sticky and contain considerable sand are as a rule of the highest strength. The Laramie clays associated with the lignite average about 150, and the Benton and Pierre clay shales a little over 100. The Tertiary clays show a very wide variation, the sandy clays having a strength of from 40 to 70 pounds, and the fine white plastic clays from 100 to 300 pounds. Some of the most plastic clays, in fact, those of exceptional plasticity, have a strength of about 150 pounds, while those containing a little more sand, although of essentially the same composition, show greater tensile strengths. This may be due in part to the cracking caused by excessive shrinkage of the finer clays, and it may be that the values determined do not represent their true bonding power, which is best determined by mixing a certain per cent of sand with them.

Ries[2] believes the tensile strength to depend mainly on the texture of the clay, which affects the coherence of the interlocking grains. Thus clays in which the grains are of varying sizes are stronger than those which are coarse grained or extremely fine

[1] N. J. Geol. Survey, Vol. VI, p. 86.
[2] N. J. Geol. Survey, Vol. VI, pp. 86-90.

grained. Grimsley and Grout[1] take a different view, and hold that the soluble salts in clays are most effective as bonding agents. From the examinations they have made there can be no doubt as to the influences of soluble sales, but their objections to Ries' views do not seem to have much weight, and the texture of the clays appears, from the writer's tests, to be the most important factor in determining their strength.

Burned Clay. In the tests carried on by the Iowa Geological Survey some of the briquettes were burned for an hour and a half at a temperature of 800 degrees C. (1472 degrees F.) and then broken. The results were of little value. An attempt was made to test the strength of some briquettes of North Dakota clays, burned at the temperature that would give the best results for the purpose for which the clay could be used, but the results were of no value, as it was impossible to burn such large briquettes properly in a small laboratory furnace.

Also the strength of the burned ware depends upon many factors, such as process of manufacture, amount of grog, temperature and time of burning, and condition of the kiln atmosphere, factors that could not be duplicated in the laboratory atmosphere. Therefore, although the strength of the burned ware is, of course, very important, it was deemed impracticable to try to determine it otherwise than by inspection of the small bricklets burned at different temperatures.

Shrinkage. All clays shrink more or less when dried from a wet and plastic to a dry, firm condition. If heated above red heat they shrink still more. The contraction due to drying is known as air shrinkage, and that due to burning as fire shrinkage. Air shrinkage varies from 2.5 to 10 per cent and fire shrinkage from 1 to 15 per cent.[2]

Air Shrinkage. Air shrinkage is due to the loss of tempering water. This not only occupies the pores of the clay, but forms a thin coating around each clay particle, separating it from its neighbor. By the loss of this water, the grains of clay are drawn nearer to each other until they come in contact, water then remaining only in the pores. This moisture is only driven off at the boiling point, but its loss is not accompanied by any further shrinkage, that being due entirely to the loss of water separating the grains. The more the grains of clay are separated when wet, that is, the more tempering water used, the greater the shrinkage on drying.

[1]West Va. Geol. Survey, Vol. III, p. 58.
[2]Wheeler, Mo. Geol. Survey, Vol. XI, p. 115.

This principle, however, does not apply when comparing different clays. Some which have a high absorption may have a low shrinkage, and vice versa. Ordinarily sandy clays have low shrinkage, and fine clays have a high shrinkage. The shrinkage is more dependent on the size and character of the grain. In sandy clays the pores are of large size and the water is easily carried from the interior of the ware to the surface, where it is evaporated and the material is thus dried uniformly throughout. With fine-grained clays, the water is retained by the mutual attraction between it and the clay particles, and the surface of the ware dries before the interior. The surface thus shrinks faster than the interior, and the ware is apt to warp or check. The more plastic clays, which have as a rule the highest shrinkage, also generally have the highest tensile strength, which gives them the power to resist the strains produced by drying. Sometimes, in fact very often, it is necessary to grog, that is, add sand or some non-shrinkable substance to the clay, to keep it from shrinking too much; and it also serves a double purpose by making the clay more porous so that the water is drawn to the surface more easily.

The air shrinkage of the clays tested was determined by measuring the dimensions of bricklets when wet and when dry; and also from the measurements of the wet and dry briquettes used for tensile strength tests. To complete the drying, the bricklets were kept in a hot air bath at approximately boiling point for a couple of hours. For the best results the bricklets should be as large (as near the full size brick) as possible. It was, however, impracticable to make tests on large size bricklets, and those used measured when wet 1 by 2 by ½ inches.

Fire Shrinkage. When a clay is heated to red heat, the combined water is driven off, and this is accompanied by a little shrinkage. With a loss of moisture and other volatile constituents the clay is left in a porous condition, and has shrunk but little. Then at a still higher heat, from 1200 to 1600 degrees F.,[1] depending on the nature and refractoriness of the material, the shrinkage becomes more pronounced. The clay gradually contracts, so as to eliminate the pore space. As the point of incipient fusion is reached (when the more fusible components of the clay fail) the shrinkage becomes very much more rapid, until the clay has completely vitrified, all the pores are filled and the maximum shrinkage has been reached.

[1]Wheeler, Mo. Geol. Survey, Vol. XI, p. 17.

The cause of the shrinkage is at first due to the loss of the combined water and other volatile matter present. In the shrinkage following this the texture of the clay seems to play the most important part. The temperature at which the shrinkage takes place is dependent on the chemical composition, but the amount of shrinkage is a function of the size and character of the grain. The finer the grain the more the shrinkage. Some of the impure particles such as limestone and quartz sand expand on heating, so that instead of a shrinkage an expansion may result. The effect of leav-lime pebbles in the clay is often seen after the burning, the brick containing them swelling so as sometimes to burst. To a lesser degree, sand has the same effect. This property of expansion possessed by sand is utilized in grogging clays which have too high a fire shrinkage.

The determination of the shrinkage is important, as it is directly applicable to the production of ware of certain definite size, the size of the moulds being based on the total air and fire shrinkage. To be of direct practical value, the clay should, of course, be tempered and grogged just as it is to be used.

In determining the fire shrinkage the same bricklets were used that were employed for the air shrinkage determination. These were burned at different temperatures, and after burning were measured and the fire shrinkage, based on the dimensions of the freshly moulded brick, calculated.

The shrinkage tests of the North Dakota clays were not at all exceptional, except some very fine, highly calcareous clay, containing also considerable magnesium, from the buttes around Sandcreek, which are undoubtedly Tertiary in age. A sample (No. 303) from here required 61.8 per cent of water to bring it up to its best plasticity. In drying it shrank 19 per cent and some of the pieces even more than that. In drying it cracked to pieces so as to render the clay valueless. The reason of the extraordinary high shrinkage is not known, but is probably due to the extreme fineness of the clay; and also the chemical composition, being high in lime and magnesia, which affect the absorption. The composition of the clay is as follows:

Silica	55.30
Ferric oxide	3.65
Alumina	15.21
Lime	3.94
Magnesia	4.22
Volatale matter	10.89

Fusibility. The fusibility of a clay, the temperature at which it changes to a liquid condition, is a most important point to determine. In burning wares, they should not, of course, be carried up to this point, else they are spoiled. The temperature of fusion of a fire clay determines the rank of the clay and the use to which it can be put.

Ordinarily a substance or mineral of a definite composition melts, under uniform conditions, at the same temperature. Clay is, however, not of definite composition, and therefore does not melt at a constant temperature. It is composed of several minerals all of which have different melting points; also the various ingredients in these minerals react on one another and form compounds which may melt at a lower point than either alone. These facts make the fusion of clays a very complex process.

After the water is driven off and the temperature raised to a good red heat, some of the more fusible of the impurities of the clay fuse and bind the more infusible particles together. The clay will have shrunk to a compact, dense body, which is as hard as glass. This stage is called incipient fusion. On heating still further other constituents begin to fuse, the pores are all filled, and the maximum shrinkage is obtained. The fracture is perfectly smooth and dense, and the clay is very hard and translucent in thin pieces. This is the stage of vitrification. If the temperature is raised still higher, the heat becomes so intense that finally the clays begin to soften completely and to warp and flow, so that the shape of the ware is destroyed. This is the point of viscosity. These several points or stages are not definitely marked, but grade one into the other.

The range of temperature between incipient fusion and viscosity is important. In many calcareous clays these points are within 27.7 degrees C. or 50 degrees F. of each other.[1] This is true of the sandy surface clays of North Dakota, which contain much sand and considerable lime. They do not become dense at a low temperature as most of the Laramie clays, but almost as soon as they are incipiently fused, they are also melted down to a greenish slag, the change taking place within three or four cone numbers (100 to 150 degrees F.). On the other hand, some of the finer grained, stratified clays, although they may fuse at as low a temperature, vitrify at a much lower.

The range between the two points in the more refractory clays may be 377.7 degrees C. (700 degrees F.) to 444.4 de-

[1] Ries, N. J. Geol. Survey, Vol. VI, p. 98.

gress C. (800 degrees F.) apart.[1] Some of the fine-grained, plastic refractory clays of the Tertiary formation possess this range and some even a higher. A selected sample from a deposit between Gladstone and Dickinson north of the railroad track, which is very plastic and burns to a dense white body is incipiently fused at cone 1 (2102 degrees F.), completely vitrified at cone 8 (2354 degrees F.), and having a dense, hard body with an absorption of less than half a per cent, but does not become viscous until cone 26 (3002 degrees F.). Many of the clays of this horizon show a range of from 600 to 800 degrees F. The more coarse textured clays of approximately the same composition do not reach incipient fusion until very high temperatures and some of them are unaffected at 3000 degrees F.

This factor is of practical importance, as it is often necessary to burn wares hard and dense or vitrify them. But this should of course be done without injuring the wares by bringing them near the point of viscosity. It is impossible to control the temperature of the kiln within a small range. Thus if clay has its points of incipient fusion and viscosity near together, either some of the ware will be melted down, or will be underburned, while a clay in which these points are widely separated may be safely vitrified without danger of the ware losing its shape.

The temperature of viscosity, aside from the range between it and that of incipient fusion, is of importance in that it determines whether or not the clay can be used at high temperatures, or whether it is a fire clay. This term fire clay has been badly misused. A clay that is refractory enough for some purposes, is not for others, but because its fusibility is high enough for the first purpose it will probably be called a fire clay. Dr. Ries uses the following classification of clays in his reports, based on their refractoriness:[2]

(1) "Highly refractory clays, those whose fusing point is above cone 33.

(2) Refractory clays, those whose fusing point ranges from cone 31 to 33, inclusive.

(3) Semi-refractory clays, those whose fusion point lies between cones 27 and 30 inclusive.

(4) Clays of low refractoriness, those whose fusion point lies between cones 20 and 26, inclusive.

(5) Non-refractory clays, fusing below cone 20.

[1]Ries, Ibid.
[2]Ibid, p. 100.

The temperature of fusion depends, first, upon the chemical and mineralogical composition, the amount and kind of fluxes and their condition; and second, the texture of the clay, its porosity and size of grain.

The ordinary fluxing agents are the alkalies, iron, lime and magnesia. In a very general way the fusibility of the clay is proportional to the amount of fluxes, ordinary clays with 10 to 15 per cent of fluxes fusing at temperatures from 2,000 degrees to 2,200 degrees F., while refractory clays, which fuse at temperatures over 3,000 degrees F. seldom have more than 1 or 2 per cent. All of these elements do not have the same effect, as has already been discussed in Chapter II. Again, the condition of each of the elements, the state of oxidation and the combination in which it exists, plays an important part. Silica and titanium have been shown to be fluxes at high temperatures. Seger also states that the ordinary fluxes have a more powerful influence on a clay high in silica than on one high in alumina. Also that a mixture of these fluxing elements is more powerful than they are alone.

The texture of the clay has also a very important influence on the fusibility. A compact, fine-grained clay will fuse at a much lower temperature than one of essentially the same composition but of a porous, coarse, sandy texture. In the first place, the porous clay does not conduct the heat so readily to the interior as does a dense one. Then, in a coarse grained clay the surfaces of grains fuse together, and these fused coverings protect the inside of the larger grains, which form a sort of skeleton holding the clay in shape.

This principle has been well illustrated in the fusibility tests on some of the more refractory North Dakota clays. Two samples of Tertiary clays have about the same compositions:

	(1)	(2)
Silica	73.90	73.20
Alumina	16.49	18.56
Ferric oxide	1.25	0.50
Lime	0.29	0.29
Magnesia	0.46	0.52
Alkalies	1.44	0.74
Water and volatile matter	5.22	5.93

Number one, which is fine-grained and plastic, is incipiently fused at cone 8, vitrified at cone 15, and becomes viscous at over cone 25. The other is a sandy clay, consisting of grains of pure quartz covered over with kaolin; it was unaffected at cont 25. The

grains of quartz were held firmly in a bond of the hard burned kaolin, which had attacked the outside of quartz grains but had not affected their interior.

The temperature of fusion of a clay may be obtained by a pyrometer or by means of test pieces made up to a definite composition, and which melt at the same temperature under the same condition, such as Seger cones. The pyrometer most extensively employed both in measuring the temperature of fusion in the laboratory and the temperature of the kiln in actual practice, is the thermo-electric pyrometer. This is based on the principle that the electric current generated by heating a couple, made of two dissimilar substances, is dependent on the temperature, although not directly proportional. The junction of the pyrometer in use, is made of platinum and an alloy of 90 per cent platinum and 10 per cent rhodium or iridium. Leads of copper wire are fastened to the free ends of the couple and carried to a galvanometer. Here the current generated is measured and the temperature calculated. This instrument is delicate and must be used carefully. This, as well as its cost, $160, has prevented its coming into general use.

Seger cones are, on the other hand, not only convenient for rough measurement, but are cheap. They consist of small triangular pyramids about two and a half inches long, the base of which is about five-eighths of an inch wide, and the top flattened. They are made up of kaolin, feldspar, quartz, marble and ferric oxide, in different proportions, so as to form a regular series which melt at different temperatures a few degrees apart. The series now consists of 58 numbers, Seger's original set being enlarged by Cramer and Hecht. The fusion point of the lowest is 500 degrees C. (1094 degrees F.), and increasing by steps of 20 degrees C., or 36 degrees F., except the lowest twelve which have an interval of 30 degrees C., to the highest, cone 36, which melts at 1850 degrees C. or 3362 F. The melting point is reached when the tip of the cone bends over and touches the base. In general, when used correctly they have been very successful, and their use is increasing. They may be obtained from Messrs. Seger and Cramer of Berlin for about 2½ cents each, including duty and express, or numbers 010 to 35 from Prof. Edward Orton, Jr., of Ohio State University, Columbus, Ohio, at one cent apiece.

The following is a list of the cones showing their composition and melting points:

Composition and Fusing Points of Segar Cones

No. of cone.	Composition			Fusing point °F.	°C.
.022	$0.5Na_2O$ $0.5PbO$		$2.0\ SiO_2$ $1.0\ B_2O_3$	1,094	590
.021	$0.5Na_2O$ $0.5PbO$	$0.1\ Al_2O_3$	$2.2\ SiO_2$ $1.0\ B_2O_3$	1,148	620
.020	$0.5Na_2O$ $0.5PbO$	$0.2\ Al_2O_3$	$2.4\ SiO_2$ $1.0\ B_2O_3$	1,202	650
.019	$0.5Na_2O$ $0.5PbO$	$0.3\ Al_2O_3$	$2.6\ SiO_2$ $1.0\ B_2O_3$	1,255	680
.018	$0.5Na_2O$ $0.5PbO$	$0.4\ Al_2O_3$	$2.8\ SiO_2$ $1.0\ B_2O_3$	1,310	710
.017	$0.5Na_2O$ $0.5PbO$	$0.5\ Al_2O_3$	$3.0\ SiO_2$ $1.0\ B_2O_3$	1,364	740
.016	$0.5Na_2O$ $0.5PbO$	$0.55Al_2O_3$	$3.1\ SiO_2$ $1.0\ B_2O_3$	1,418	770
.015	$0.5Na_2O$ $0.5PbO$	$0.6\ Al_2O_3$	$3.2\ SiO_2$ $1.0\ B_2O_3$	1,472	800
.014	$0.5Na_2O$ $0.5PbO$	$0.65Al_2O_3$	$3.3\ SiO_2$ $1.0\ B_2O_3$	1,526	830
.013	$0.5Na_2O$ $0.5PbO$	$0.7\ Al_2O_3$	$3.4\ SiO_2$ $1.0\ B_2O_3$	1,580	860
.012	$0.5Na_2O$ $0.5PbO$	$0.75Al_2O_3$	$3.5\ SiO_2$ $1.0\ B_2O_3$	1,634	890
.011	$0.5Na_2O$ $0.5PbO$	$0.8\ Al_2O_3$	$3.6\ SiO_2$ $1.0\ B_2O_3$	1,688	920
.010	$0.3K_2O$ $0.7CaO$	$0.2\ Fe_2O_3$ $0.3\ Al_2O_3$	$3.50SiO_2$ $0.50B_2O_3$	1,742	950
.09	$0.3K_2O$ $0.7CaO$	$0.2\ Fe_2O_3$ $0.3\ Al_2O_3$	$3.55SiO_2$ $0.45B_2O_3$	1,778	970
.08	$0.3K_2O$ $0.7CaO$	$0.2\ Fe_2O_3$ $0.3\ Al_2O_3$	$3.60SiO_2$ $0.40B_2O_3$	1,814	990
.07	$0.3K_2O$ $0.7CaO$	$0.2\ Fe_2O_3$ $0.3\ Al_2O_3$	$3.65SiO_2$ $0.35B_2O_3$	1,850	1,010
.06	$0.3K_2O$ $0.7CaO$	$0.2\ Fe_2O_3$ $0.3\ Al_2O_3$	$3.70SiO_2$ $0.30B_2O_3$	1,886	1,030
.05	$0.3K_2O$ $0.7CaO$	$0.2\ Fe_2O_3$ $0.3\ Al_2O_3$	$3.75SiO_2$ $0.25B_2O_3$	1,922	1,050
.04	$0.3K_2O$ $0.7CaO$	$0.2\ Fe_2O_3$ $0.3\ Al_2O_3$	$3.80SiO_2$ $0.20B_2O_3$	1,958	1,070
.03	$0.3K_2O$ $0.7CaO$	$0.2\ Fe_2O_3$ $0.3\ Al_2O_3$	$3.85SiO_2$ $0.15B_2O_3$	1,994	1,090
.02	$0.3K_2O$ $0.7CaO$	$0.2\ Fe_2O_3$ $0.3\ Al_2O_3$	$3.90SiO_2$ $0.10B_2O_3$	2,030	1,110
.01	$0.3K_2O$ $0.7CaO$	$0.2\ Fe_2O_3$ $0.3\ Al_2O_3$	$3.95SiO_2$ $0.05B_2O_3$	2,066	1,130
1.	$0.3K_2O$ $0.7CaO$	$0.2\ Fe_2O_3$ $0.3\ Al_2O_3$	$4SiO_2$	2,102	1,150
2.	$0.3K_2O$ $0.7CaO$	$0.1\ Fe_2O_3$ $0.4\ Al_2O_3$	$4SiO_2$	2,138	1,170
3.	$0.3K_2O$ $0.7CaO$	$0.05Fe_2O_3$ $0.45Al_2O_3$	$4SiO_2$	2,174	1,190
4.	$0.3K_2O$ $0.7CaO$	$0.5\ Al_2O_3 4SiO_2$		2,210	1,210

COMPOSITION AND FUSING POINTS OF SEGAR CONES

No. of cone	Composition		Fusing point °F.	°C.
5.	$0.3K_2O$ / $0.7CaO$	$0.5Al_2O_3 5SiO_2$	2,246	1,230
6.	$0.3K_2O$ / $0.7CaO$	$0.6Al_2O_3 6SiO_2$	2,282	1,250
7.	$0.3K_2O$ / $0.7CaO$	$0.7Al_2O_3 7SiO_2$	2,318	1,270
8.	$0.3K_2O$ / $0.7CaO$	$0.8Al_2O_3 8SiO_2$	2,354	1,290
9.	$0.3K_2O$ / $0.7CaO$	$0.9Al_2O_3 9SiO_2$	2,390	1,310
10.	$0.3K_2O$ / $0.7CaO$	$1.0Al_2O_3 10SiO_2$	2,426	1,330
11.	$0.3K_2O$ / $0.7CaO$	$1.2Al_2O_3 12SiO_2$	2,462	1,350
12.	$0.3K_2O$ / $0.7CaO$	$1.4Al_2O_3 14SiO_2$	2,498	1,370
13.	$0.3K_2O$ / $0.7CaO$	$1.6Al_2O_3 16SiO_2$	2,534	1,390
14.	$0.3K_2O$ / $0.7CaO$	$1.8Al_2O_3 18SiO_2$	2,570	1,410
15.	$0.3K_2O$ / $0.7CaO$	$2.1Al_2O_3 21SiO_2$	2,606	1,430
16.	$0.3K_2O$ / $0.7CaO$	$2.4Al_2O_3 24SiO_2$	2,642	1,450
17.	$0.3K_2O$ / $0.7CaO$	$2.7Al_2O_3 27SiO_2$	2,678	1,470
18.	$0.3K_2O$ / $0.7CaO$	$3.1Al_2O_3 31SiO_2$	2,714	1,490
19.	$0.3K_2O$ / $0.7CaO$	$3.5Al_2O_3 35SiO_2$	2,750	1,510
20.	$0.3K_2O$ / $0\ 7CaO$	$3.9Al_2O_3 39SiO_2$	2,786	1,530
21.	$0.3K_2O$ / $0.7CaO$	$4.4Al_2O_3 4\ SiO_2$	2,822	1,550
22.	$0.3K_2O$ / $0.7CaO$	$4.9Al_2O_3 49SiO_2$	2,858	1,570
23.	$0.3K_2O$ / $0.7CaO$	$5.4Al_2O_3 54SiO_2$	2,894	1,590
24.	$0.3K_2O$ / $0.7CaO$	$6.0Al_2O_3 60SiO_2$	2,930	1,610
25.	$0.3K_2O$ / $0.7CaO$	$6.6Al_2O_3 66SiO_2$	2,966	1,630
26.	$0.3K_2O$ / $0.7CaO$	$7.2Al_2O_3 72SiO_2$	3,002	1,650
27.	$0.3K_2O$ / $0.7CaO$	$20Al_2O_3 200SiO_2$	3,038	1,670
28.	$Al_2O_3 10SiO_2$		3,074	1,690
29.	$Al_2O_3 8SiO_2$		3,110	1,710
30.	$Al_2O_3 6SiO_2$		3,146	1,730
31.	$Al_2O_3 5SiO_2$		3.182	1,750
32.	$Al_2O_3 4SiO_2$		3,218	1,770

No. of cone.	Composition	Fusing point °F	°C.
33.	$Al_2O_3 3SiO_2$	3,254	1,790
34.	$Al_2O_3 2.5SiO_2$	3,290	1,810
35.	$Al_2O_3 2SiO_2$	3,326	1,830
36.	$Al_2O_3 1.5SiO_2$	3,362	1,850

In using them, a few are placed in the kiln, set in on slabs of fire clay and inclined slightly in the directión in which it is desired that they should bend. From a peep hole they can be easily watched and the temperature determined by noting which is the highest number to bend over, and the lowest which does not, the temperature therefore lying between these two numbers. If they are treated reasonably, the temperature being raised gradually, and are protected from drafts of air, the results are very good.

In determining the fusion point, the clays were ground through a 30-inch screen and mixed to their best plasticity. It was then spread out into a flat plate about one-half inch thick and cut into pieces of the same size and shape as the Seger cones. The cones were thoroughly dried and first burned at a gentle heat. To test, they were set with the Seger cones in a wet slab of clay, and after drying were placed in the furnace and burned. The clay cones were burned to several temperatures. That at which the cone bent over to the base being taken as the point of viscosity, the other points were determined by inspection of the fracture, shrinkage and absorption tests. In this way fair results were obtainable.

The laboratory was not equipped with furnaces reaching a heat of over 3,000 degrees F., so that fusion points of the clays which did not become viscous at that temperature could not be determined. This was unfortunate, as many of the clays were not affected at 3,000 degrees F., and it would be interesting and desirable to know the exact temperature at which they did fail.

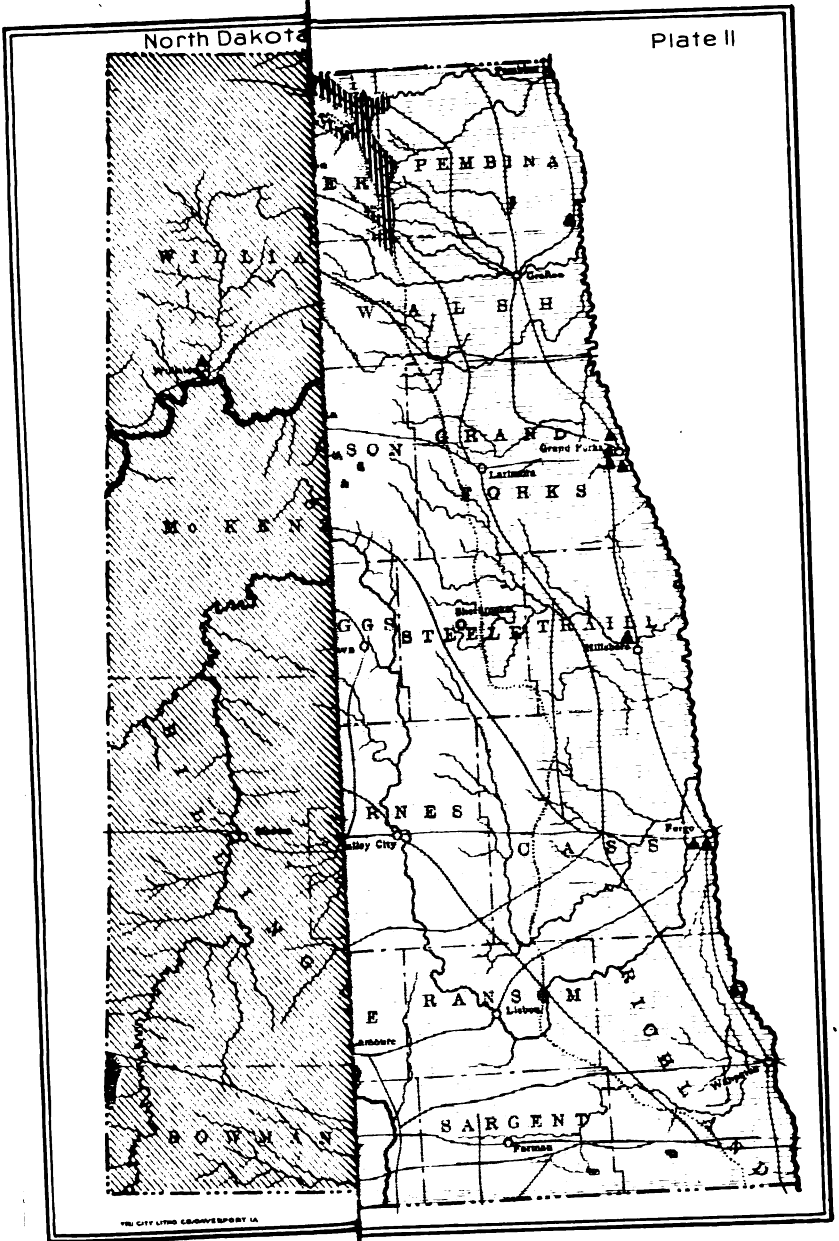
In carrying out the above tests some definite purpose for which the clay could be used should be borne in mind. The influence of one property on another noted. Thus the testing may be made of the most value, and the bearing of the different properties on the value and uses of the clay determined.

PART II

STRATIGRAPHY OF NORTH DAKOTA CLAYS

BY

A. G. LEONARD



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STRATIGRAPHY OF NORTH DAKOTA CLAYS

BY

A. G. LEONARD.

CONTENTS.

CHAPTER IV.

STRATIGRAPHY OF THE NORTH DAKOTA CLAYS.

Most of the geological formations occurring in North Dakota contain clays of economic value. These are found in all parts of the state and there is no large section without some kind of clay suitable for brick, hollow blocks or other manufactured products. The geological formations found in North Dakota are shown in the following table:

TABLE OF NORTH DAKOTA GEOLOGICAL FORMATIONS

	Formations occurring in North Dakota
Cenozoic Era:	
Pleistocene Period, represented by............	Drift and lacustrine deposits
Tertiary Period, represented by	Oligocene Fort Union
Cretaceous Period, represented by	Laramie Fox Hills Pierre Niobrara Benton Dakota
Paleozoic Era:	
Devonian Period, Silurian Period, Cambrian Period, represented by.........	Shales, limestones and sandstones
Archean Era, represented by	Granites.

No beds older than the Cretaceous appear at the surface anywhere within the state, and their presence is known only through well records. The Archean granite and the rocks of the Paleozoic have been struck in wells sunk in the Red River Valley, but since they do not outcrop they will not receive further consideration at this time.

CRETACEOUS

COLORADO FORMATION.

Benton Shale.—The oldest member of the Cretaceous that is found exposed at the surface is the Benton shale, which rests upon the Dakota sandstone. In the wooded escarpment bordering the Red River Valley on the west, for thirty or forty miles south of the

international boundary, the rivers have cut deep valleys along which the Cretaceous beds are exposed. On the Pembina river there occur certain shales, below the calcareous beds of the Niobrara, which have been referred to the Benton subdivision of the Colorado formation. The shale outcrops at the Mayo brick plant, in T. 163, R. 57, section 33, opposite the mouth of the Little Pembina.

The section exposed here is as follows:

		Feet.
6.	Drift	6-8
5.	Buff, chalky marl	20
4.	Calcareous clay and marl, light to dark gray in color	28
3.	Marl in more massive beds and breaking into large, irregular blocks, on broken face shows thin and somewhat uneven laminae one-sixteenth to one-eighth inches thick	6-8
2.	Calcareous clays and marls, composed of alternating layers of more calcareous and marly clays and less calcareous clays; light to dark gray in color	80
1.	Clay shale, poor in lime, forming when wet a stiff, plaster clay; light to dark gray; contains some gypsum crystals and calcareous nodules	150

The lowest member in the above section (No. 1) is believed to be Benton, although careful search has failed to reveal any fossils in these beds. Numbers 2 to 5 undoubtedly belong to the Niobrara, as indicated by the fossils.

While the Benton shale is best exposed in the section opposite the mouth of the Little Pembina, it extends up the valley of the Pembina several miles above this point, and outcrops about one mile from the Mayo brick plant. The shale was also seen on the east side of the valley of the Little Pembina, about two miles above its confluence with the major stream.

The outcrops of the Benton shale are confined to the Pembina and Little Pembina rivers, where these have eroded their valleys through the overlying formations and some distance into the underlying beds. The other rivers of the Pembina Mountain region, such as the Tongue, have not cut their channels down to the Benton formation.

The shales are being used for the manufacture of brick and hollow blocks at the Mayo brick plant and the clay is found to be well suited for that purpose.

Upham[1] states that in the vicinity of the southern bend of the Sheyenne river there are scanty exposures of Cretaceous beds

[1] Mono. U. S. Geol. Survey, No XXV, p. 92.

which contain thin seams of lignite and may be Fort Benton. It is not unlikely, however, that these beds belong to the Pierre.

Niobrara.—The upper member of the Colorado formation is the Niobrara and it is often impossible to draw any sharp line of separation between this and the underlying Benton. The Niobrara, however, is usually characterized by a greater or less thickness of calcareous and chalky strata.

Outcrops are confined to the northeastern corner of the state, in the Pembina Mountains, where the beds are exposed along the Pembina, Little Pembina, Tongue and other rivers.

The section occurring at the cement mill on the Tongue river is as follows:

	Feet.
6. Unexposed to top of hill, drift in part	30
5. Clay shale, gray, irregularly jointed, weathers into thin flakes; contains small yellow spots and blotches, also iron pyrites concretions. (Pierre.)	70
4. Unexposed, probably in part the same as No. 3	70
3. Shale, dark brown to brownish black, carbonaceous, contains a few thin, white seams; highly jointed, the joint cracks being filled with gypsum	27 to 30
2. Clay, in black and white layers. A black bed rests directly on the cement marls of No. 1. The lower layer for about one foot above the marl contains much gypsum scattered in crystals and crystalline masses through the clay. Also contains much limonite, which strains the underlying marl. In places the black clay grades into the white, as though the latter were derived from the black by leaching. The white clay also contains black patches, as though these were remnants of the original black shale	6 to 8
1. Calcareous clay or marl containing much bituminous material and when fresh having a strong petroleum odor; color, gray with many small white spots formed by the lime. Fossils not uncommon. Contains several thin seams of lignite one to three inches thick	80

In the above section the lowest member (No. 1) is the only one belonging to the Niobrara, since the overlying dark and white bands are doubtless to be classed with the Pierre.

The North Pembina, which empties into the main stream at the "Fish Trap," about four miles above the mouth of the Little Pembina, has a narrow, deep and V-shaped valley. In the latter, three miles above the Fish Trap, there is an outcrop where the following section is exposed:

	Feet.	Inches.
9. Shale, Pierre	110	
8. Unexposed	20 to 30	
7. Carbonaceous clays, black and brown, alternating with white or yellowish clay seams. Black layers 8 to 14 inches thick, white layers vary from 1 to 4 inches	8 to 15	
6. Layer containing much gypsum and some limonite		8
5. Marl, chalky, light colored, containing many cracks filled with gypsum		8
4. Limonite seam, with gypsum crystals		1
3. Gypsum bed		1 to 2
2. Marl, somewhat chalky in appearance, yellowish or buff in color		18
1. Cement marls, gray, which here rise from 300 to 400 feet above the Pembina river at Mayo's brick plant. Unexposed except near top. Grade above into No. 2.		

Numbers 1 to 5 of the above section belong to the Niobrara. These beds also appear at many points along the Little Pembina as far up the valley as the sharp bend to the west and beyond. The excellent exposure on the Pembina, opposite the mouth of the Little Pembina, has been described on a previous page. Outcrops of the Niobrara are much less common on the Tongue river, although the valley is cut deeply into the beds of that formation. But the sides are thickly overgrown with underbrush and timber, so that good exposures of the Cretaceous clays and marls are rare.

At Valley City there is exposed below the Pierre shale a light-colored and highly calcareous clay, which probably belongs to the Niobrara. Both in appearance and composition it is distinctly unlike the beds referred to the Pierre. The clay outcrops near the base of the cut along the Soo railroad, one and a quarter miles east of Valley City, where twenty feet of light gray and cream colored clay appear. The same light colored calcareous clays are seen along the Sheyenne river at the sharp bend one mile south of the town, where the stream cuts against the bluff. Here are expose 100 feet of light gray clay, breaking into thick, irregular pieces, and overlain by twenty feet of black shale which is undoubtedly Pierre. The upper portion, for several feet below the dark shale, is cream colored and more calcareous than the lower beds.

An analysis of these more calcareous layers gave the following result, the specimen being air dried:

	Per Cent.
Carbonate of lime	45.00
Carbonate of magnesia	3.00
Silica	30.70
Iron and magnesia oxides	15.20
Materials undertermined and moisture	6.10
	100.00

As shown in the foregoing sections, the Niobrara is formed of more or less calcareous clay shales and marls, the latter in some places forming beds of impure chalk. The color ranges from light to dark gray and buff. The calcareous beds have a characteristic speckled or mottled appearance, due to the white spots of lime-carbonate which thickly dot the surface.

In many of the outcrops the beds near the surface are yellowish or buff through a thickness varying from two to twenty feet. These pass below into the gray marls and there is no sharp line of separation between them. They appear to be the result of weathering and are found where the beds have been exposed to percolating waters. The marls have been oxidized and changed to a buff color.

Where protected by a considerable thickness of the overlying Pierre shales, as at the cement mill, the buff beds are absent and the gray marls of the Niobrara extend up to the bottom of the Pierre.

Near the base of the bluff at the cement mill there is a seven foot layer which is quite uniform in chemical composition and approaches closely that of a natural Portland cement rock. A large series of analyses show that the composition of this layer lies within the following ranges:

	Per Cent.
Silica	9 to 15
Alumina	4 to 8
Iron oxide	2 to 3
Carbonate of lime	63 to 75
Carbonate of magnesia	1 to 2.5

The marl beds above this vary widely in composition, the percentage of lime carbonate ranging all the way from 20 to 75 per cent. The layers very poor in lime are seldom more than one or two inches thick, while those highest in lime are usually not over two feet in thickness. These chemically different beds alternate one with another and there is no regular increase or decrease in

the lime content toward the top or bottom of the section, the changes in composition being quite abrupt.

Another feature of some of these gray marls is that they are composed in large part of the calcareous shells of the microscopic Foraminifera so characteristic of the chalk. Two species are especially abundant in the chalk deposits, *Globigerina cretacea* and *Textularia globulosa,* and both of these are found in large numbers in the marls of the Niobrara. Some of the beds of the latter, occurring in North Dakota, are therefore an impure, argillaceous chalk.

The clays of the Niobrara which are exposed in the state are most of them too calcareous to be suitable for the manufacture of brick or other clay products.

MONTANA FORMATION.

Pierre Shale.—The lowest member of the Montana formation, the Pierre shale, has a wide distribution in North Dakota, being found throughout the central and eastern portions, west of the Red River Valley. In most places it is covered by glacial drift to a greater or less depth and appears at the surface only along stream valleys or where it had been exposed by the removal of the overlying deposit.

The beds forming the lower portion of the Pierre and resting directly upon the Niobrara are well shown in the sections on the Tongue and North Pembina rivers, given on a previous page.

It appears from these that the base is composed of black to dark brown carbonaceous clay shales, in which there are many seams of white clay. These black and white beds have a total thickness of thirty to forty feet or over. The black layers vary in thickness from eight to fourteen inches and the white from one to four inches. These alternating black and white strata are very persistent and cover a large area.

Their outcrops in the Pembina Mountains occur at intervals for a distance of at least thirty miles south of the international boundary, and the same black and white layers are found at Valley City, appearing in the bluffs near the Normal School and elsewhere. They overlie the light colored calcareous clays described on a previous page.

These beds at the base of the Pierre are sharply marked off from the underlying mottled gray marls of the Niobrara, not only in color and texture but in chemical composition, being very low in lime and high in silica.

Above these beds occur the typical Pierre shales, bluish gray in color, jointed, weathering into small flaky fragments. The fragments commonly show yellow spots or stains of iron oxide.

The top of the Pierre is exposed near the extreme western boundary of the state, along Little Beaver creek, in Bowman county. A small area is found here, surrounded on all sides by Laramie or Fort Union. The beds have probably been elevated by an anticlinal fold and the overlying formation has been eroded. Seventy-five feet of gray, jointed clay shale appear in a cut bank on the creek at Mr. Ash's place, in T. 132, R. 107, section 23. These shales, which represent the top of the Pierre, are filled with numerous concretions of impure lime carbonate, varying in size from several inches to six and eight feet. The lime concretions are very rich in fossils which are characteristic of the top of the Pierre. The following were collected at this locality:[1]

Ostrea pellucida M. &. H.
Avicula linguiformis E. & S.
Inoceramus cripsi var barabini Morton.
Chlamys nebrascensis M. & H.
Yoldia evensi M. & H.
Nucula cancellata M. & H.
Lucina occidentalis Morton.
Protocardia subquadrata E. & S.
Callista deweyi M. & H.
Lunatia.
Onisomyon patelliformis M. & H.
Margarita nebrascensis M. & H.
Fasciolaria (?) (Cryptorhytis) flexicostata M. & H.
Pyrifusus.
Haminea (?) *occidentalis* M. & H.
Scaphites nodosus Owen, varieties *brevis* and *plenus.*
Nautilus dekayi Morton.

This Bowman county area of Pierre shale extends north and south along the state line, the clay of the district being known locally as "gumbo." Its extent and boundaries have not yet been determined.

With the exception of this restricted area the Pierre is not known to occur in the western part of North Dakota.

In the Pembina Mountain region it is exposed along all of the streams which have their source in the elevated region west of

[1]Identified by Mr. T. W. Stanton.

the escarpment and flow east into the Red river. Outcrops are therefore common in Cavalier and Walsh counties. The Pierre shale is excellently exposed at Milton, along the valley of the North Branch of Park river, and one and a half miles north of Niagara, along the North Branch of the Turtle river. It appears at many points along the Sheyenne river in Nelson, Griggs and Barnes counties. At Valley City the Pierre shales rise at least 120 feet above the river. They outcrop one and a quarter miles east of town in a cut along the Soo railroad, where the following section is found:

	Feet.
4. Drift and soil	1 to 3
3. Black clay shale, with yellow iron stains in spots and blotches; crumbles on exposure into thin flakes	6 to 8
2. Light gray and cream colored clay shales, containing some layers of calcareous clay	20
1. Unexposed to river	60

The light colored clays of number 2, which have been referred to on a previous page as Niobrara in age, are readily distinguished from the dark ones even at a distance, and the contrast between them can be traced for miles along the bluffs.

The same beds are exposed along the Sheyenne river at a sharp turn one mile south of Valley City, where the stream cuts against the bluff. One hundred feet of light gray clay shale, representing number 2 of the above section, and likewise probably Niobrara, are exposed here, overlain by ten to twenty feet of black shale belonging to the Pierre. The light colored shale breaks into thick, irregular pieces and not into thin fragments or flakes, as the black shale.

Along the James river, in Stutsman, Foster and Eddy counties, the Pierre shale is exposed at many points. It is also found along Pipestem creek, which empties into the James at Jamestown. Along the valley of the former it outcrops at the abrupt bend one mile south of Parkhurst, the first station north of Jamestown. Seventy-five feet of dark clay shales are here shown. They are cut by several sets of joints and show many yellow spots and blotches of iron oxide. The shales are easily broken into thin slabs with conchoidal fracture, and under the action of the weather they crumble into flaky fragments.

Similar shales outcrop on the James river in the vicinity of Jamestown, being exposed about one mile above town, five miles north, and at other localities.

The character of the Pierre is perhaps sufficiently well shown from the foregoing sections and descriptions. The bulk of the formation is composed of gray to almost black shale, very uniform in appearance over wide areas. The beds are jointed and weather into small fragments. At the base, as exposed in the Pembina Mountain region, there are thirty or forty feet of alternating black and white beds. At the top the shales contain many calcareous concretions rich in fossils. Below this upper horizon fossils appear to be rare. Of those which do occur the more common are *Baculites ovatus* Sāy, *Inoceramus sagensis* Owen, and *Scaphites nodosus* Owen. The fossils occurring at the top of the formation have already been named.

Analyses of Pierre shales from Manitoba are given in the following table:

ANALYSES OF PIERRE SHALES.[1]

	1.	2.	3.	4.
Moisture, combined water, above 100 C..	9.71	6.06	6.78	8.25
Silica	68.14	79.55	81.94	78.32
Alumina	8.18	8.35	6.52	7.11
Ferric oxide	4.10	1.90	2.40	2.59
Lime	1.67	1.50	.80	.91
Magnesia	1.65	1.02	.93	1.28
Alkalies	2.01	1.17	1.30	1.11
Sulphur trioxide	.39	not given	.16	.05
Carbon dioxide	1.44	not given	traces	traces
Organic matter	3.00	not given	traces	traces

(1.) Odanah shale free from sand at La Riviere brick works.

(2.) Compact, light bluish-gray, tough, smooth shale from the Pierre formation near Souris City, Souris river.

(3.) Compact, light gray, fissile shale, free from sand, from south bank of Big Creek, a branch of Big Grassy river, northwest corner of section 8, T. 17, R. 15 W., Riding Mountain.

(4.) Pierre shale, banks of the Assiniboine river, three miles north of Virden.

While the Pierre shale has not been used for brick making in North Dakota there is no reason why it should not be utilized for this purpose, since it is well suited for the manufacture of a variety of clay products. These shales are used for making dry pressed brick at La Riviere, Manitoba, and tests made at the University, in the laboratory of the School of Mines, show that they are adapted for that purpose.

The bricks produced from the Pierre shale at La Riviere are very refractory. When the shale is finely pulverized and mixed

[1]Preliminary Report on the Industrial Value of the Clays and Shales of Manitoba, by J. Walter Wells, 1905.

with more fusible clays to render it less refractory, it may make a good paving brick which is dense, compact, vitrified, impervious to water and resisting abrasion.

There are a number of localities in North Dakota where the Pierre shale occurs near the railroad and which are favorably situated for the location of brick plants making use of this material. At Jamestown the Pierre outcrops within a mile of town. Where exposed at Valley City the shale is for the most part much too calcareous to be suitable for brick, but the upper, black shale might be used.

Fox Hills.—The upper member of the Montana formation is the Fox Hills. So far as known, the sandstones and clays of this period appear at the surface at only a few points in North Dakota. On the Cannon Ball river about eight miles above its mouth occurs a brown, friable sandstone, containing the fossil shells *Tancredia americana* M. & H. and *Callista* sp., possibly *Callista nebrascensis* M. & H. These are marine Cretaceous forms and the sandstone beds containing them doubtless belong to the Fox Hills.[1]

On account of the lack of exposures little is known of the character of the Fox Hills strata in this state. In South Dakota they consist largely of gray and yellow, thin-bedded sandstone, with which is associated incoherent sands and arenaceous clays. Their thickness is from 100 to 150 feet. In eastern Montana the Fox Hills is composed chiefly of clay with some sandstone. The clay is light gray to buff in color and more or less sandy. Its thickness here is about 100 feet.

LARAMIE AND FORT UNION FORMATIONS.

Though these two formations are thought to be distinct they have not yet been separated in North Dakota, and are therefore considered together. The term Laramie as used in the following pages therefore embraces all the coal-bearing strata, including the Fort Union beds, which are named from the locality where they are well exposed, near the site of the old fort at the mouth of the Yellowstone river. The flora of the Fort Union contains many species not found in the underlying Laramie and for this reason it is regarded by a number of geologists as more recent in age, and is placed in the Tertiary.

In eastern Montana the Laramie has a thickness of only 400 to 600 feet and is overlain by beds different in character and carrying

[1]Fossils were identified by Dr. T. W. Stanton.

Fort Union plants. Fossils of the latter period are found at many localities in North Dakota, and it is not unlikely that much that has been called Laramie in this state will, on further study, prove to be Fort Union.

The Laramie formation itself has aroused much discussion regarding its age, some referring it to the Cretaceous and others to the Tertiary. This uncertainty as to the age of the Laramie strata is due to the fact that the plant remains resemble those of the Tertiary, while the vertebrate life is distinctly Cretaceous. The formation is now regarded as holding a transitional position between these two periods, and is related to the Mesozoic on the one hand and to the Cenozoic on the other.

No other geological formation in North Dakota, with the possible exception of the Pierre, covers so large an area within the state. The Laramie beds occupy the entire western half, with the probable exception of the greater portion of Bottineau and McHenry counties. As will be seen from the geological map accompanying this report, the Laramie extends as far east as the eastern edge of Emmons, Burleigh, McLean and Ward counties, and perhaps further. Outcrops of the clays, sands and lignite seams are common along all the larger streams of the region, the Missouri, Little Missouri, Cannon Ball, Heart and Knife rivers, with their tributaries. Over the greater portion of Bowman, Billings, Hettinger and Stark counties the Laramie is not covered by drift and lies directly at the surface, with only a thin covering of soil. Probably the best exposures are found in the badlands of the Little Missouri, where the conditions are particularly favorable for the study of the beds.

The Laramie formation is composed of alternating layers of clay and sand, together with seams of lignite. In places the sand layers are cemented into a firm, hard sandstone, but commonly they form incoherent beds, readily crumbling in the hand. These arenaceous strata, however, resist the action of weathering agencies better than the clays, and their outcropping edges form vertical ledges, often projecting beyond the clays. The presence of the sandy beds can thus commonly be detected at a distance by the character of the slope.

Probably two-thirds of the thickness of the Laramie is made up of clays, though this varies in different places. These clay shales range in composition from very pure clays through those containing an increasing percentage of sands to beds with only a small

proportion of clay. The argillaceous strata thus graduate into the sandy layers through every intermediate mixture of clay and sand, and we have sandy clays and clayey sandstones. In some cases the change from clay shale to sand is abrupt, in others it is gradual, the clay becoming more sandy near the line of contact.

One of the most marked features of the Laramie is this rapid alternation of sand and clay strata, and the frequent occurrence of beds of lignite. The colors of the clay are white, gray, yellow, brown and red, the grays and yellows predominating. The brown layers are rich in plant remains, and it is to the presence of this carbonaceous matter that they owe their color. These varied colors give the formation its marked banded appearance and add greatly to the beauty and variety of the landscape.

Crystallized gypsum or selenite is common in the clay and in some layers this mineral is very abundant. It is particularly liable to occur in the brown layers immediately beneath the lignite seams. The crystals are often very much elongated, some being found eight and ten inches in length, and are seldom perfect, the faces being more or less etched.

Of still more frequent occurrence are the ferruginous nodules and concretions, composed either of iron pyrites or of limonite. They usually contain more or less silicious or argillaceous material, and after exposure to the weather stain the clay about them yellow. Many of the clay slopes are thickly dotted with these nodules and concretions of all shapes and sizes up to several feet in diameter. Thin, impure limonite or clay ironstone bands, yellow in color, are not uncommon in the clays.

Another feature of the Laramie formation is the presence of silicified wood, often preserving very perfectly the original structure of the trees. Large stumps several feet in diameter and fragments of the trunks and branches are common.

Beds of sand, sometimes hardened into a firm sandstone, compose a large part of the Laramie formation. The sand varies from coarse to fine and in color is usually some shade of gray, though yellows and browns are found. Mingled with the sand is a varying proportion of clay, so that it passes into an argillaceous sand and sandy clay.

The sandy strata often contain lenses and concretions of sandstone. These are made up of concentric layers, are much harder and more compact than the inclosing mass and are frequently of great size, some being observed twenty to twenty-five feet in

diameter. Many resemble large lenses of sandstone, but their concentric structure shows their true character.

Perhaps the most striking feature of the Laramie is its lignite beds, which are seldom absent from a section of any considerable thickness. These are not confined to any particular horizon or horizons, but are distributed quite uniformly from top to bottom of the formation. In the Slim Buttes of South Dakota, six feet of lignite occur twenty-six feet below the top of the Laramie, a bed ten and three-quarters feet thick forty-nine feet below and a five-foot seam occurs ninety-five feet from the top of the Laramie. The twenty-one and a half foot bed in Sentinel Butte lies 340 feet below the top and there is an eighteen inch bed 142 feet below the Tertiary. On the other hand the records of the deep wells at Medora and Dickinson show that the lignite is found well toward the base of the formation. The seams thus have a vertical range of 1,500 feet or more.

The number of seams varies considerably in different parts of the area. At some points but two or three appear, while in other localities there are ten or fifteen in a vertical distance of 250 to 500 feet, though many of them are only a few inches in thickness. Rarely are several hundred feet of Laramie strata exposed that at least one or more lignite beds are not present. In a section appearing in the bluffs of the Little Missouri near the mouth of Cherry creek there are not less than fifteen beds within a vertical range of 480 feet, having an aggregate thickness of twenty-five feet. On the other hand, in the 180 feet of Laramie clays exposed in the bluffs on the south side of the Missouri three miles below Williston the thickest of the six seams present is only three feet. The Medora well passed through 941 feet of Laramie strata without reaching their base and encountered seventeen beds with a total thickness of more than sixty feet. The Dickinson well, with a depth of about 1,075 feet, penetrated sixteen seams, their aggregate thickness being about fifty-five feet.[1]

The lignite beds vary in thickness from an inch and less to thirty-three feet. Those six, eight and ten feet thick are common; seams from ten to twenty feet thick are not rare, and those over twenty feet thick seldom occur.

There is one peculiarity of the Laramie clays and sands which cannot fail to attract the notice of even the casual observer, and that is the vast quantity of burnt and fused clay which is seldom

[1] Darton: Seventeenth Ann. Rep. U. S. Geol. Survey, Part 2, p. 663.

absent wherever there are extensive outcrops of the strata. This clay has been produced by the burning out of the beds of lignite, the heat thus generated having been sufficient to burn and often fuse the adjacent clays. This burning of the lignite has doubtless been going on for centuries and has resulted in the production of a surprisingly large amount of red clay. Bands of this material may be traced for miles along the bluffs of the stream valleys and in the buttes, representing the horizon of burned out lignite beds, portions of which are often found intact at some points.

The thickness of the Laramie in eastern Montana, not including the Fort Union, is from 400 to 600 feet. In western North Dakota the thickness of the lignite bearing beds, including both the Laramie and Fort Union, is at least 1,800 feet. The Medora well, with a depth of 941 feet, did not reach the bottom of the formation, and Sentinel Butte rises 861 feet above the curb of the well.

As already stated, numerous exposures in all parts of the area afford excellent opportunity for the study of the Laramie formation and detailed sections have been made of many of these. Since they show the character of the beds a number of these sections are here given, arranged according to the counties in which they occur.

Williams County.—The Laramie strata of this county are covered with a thick mantle of glacial drift, and it is only where the streams have cut through this to the underlying beds that they are exposed. The outcrops are thus confined to the vicinity of the streams, and most of them are near the southern border, along the Missouri river and its tributaries.

SECTION IN THE BLUFFS OF THE MISSOURI, FOUR MILES SOUTHEAST OF WILLISTON.

		Feet.	Inches.
13.	Drift, containing many boulders	1 to 10	
12.	Clay, light gray	4 to 6	
11.	Lignite seam, not well exposed	1 to 2	
10.	Clay, sandy, light gray, with yellow bands due to presence of limonite similar to Nos. 5 and 8	30	
9.	Lignite seam	..	8
8.	Sandy clay shales similar to No. 5 and containing many ferruginous sand concretions	20	
7.	Light bluish gray clay, not sandy, crumbles readily into thin laminae; much softer and more easily weathered than No. 6	2	
6.	Clay shale with peculiar vertical fracture; is broken up into long, slender and irregular columnar pieces		

	Feet.	Inches.
by numerous vertical cracks. This clay shale is harder than the clays above and below and hence resists weathering better	..	10
5. Light gray, sandy, clay shale with yellow, limonitic bands	30	
4. Lignite seam	9	
3. Light gray, sandy clay, similar to No. 1, but has fewer concretions. Contains leaf impressions and silicified wood. One silicified trunk twelve inches in diameter lies immediately above the coal seam (No. 2)	50	
2. Lignite seam	3	
1. Light gray, sandy clay, containing abundant ferruginous sand concretions scattered through the clay; selenite crystals also numerous	30	

The base of the section is about eighty feet above the river.

Ward County.—The Laramie beds of this county are likewise for the most part concealed by the drift, which in places has a thickness of 100 to 200 feet, and a very rough, hilly surface. Exposures of the underlying clays and sands are not common, but they are found along the Missouri, White Earth and Des Lacs rivers and their tributaries.

SECTION ON WHITE EARTH RIVER, ONE AND A HALF MILES NORTH OF TOWN OF WHITE EARTH.

22. Drift	2 to 6	
21. Gray, sandy clay, with large sandstone concretions	30	
20. Lignite seam		8
19. Gray clay	8	
18. Sandstone, weathering into concentric, concretionary masses, soft, gray	1	6
17. Gray, sandy clay, with yellow, ferruginous lines and bands, not well exposed	30	
16. Lignite seam		2
15. Clay, gray, sandy, with sandstone concretions	25	
14. Soft, gray, shaly sandstone	2	
13. Gray, sandy, clay, with yellow ferruginous bands	7	
12. Lignite and brown fissile shale		6
11. Gray and very sandy clay	25	
10. Lignite seam, not well exposed	2	
9. Gray clay containing much selenite	20	
8. Gray sandtone	1	6
7. Gray clay	8	
6. Yellow clay		2
5. Gray clay	3	
4. Yellow, ferruginous band		½
3. Gray clay	1	6
2. Clay, brown, fissile, with some lignite		2
1. Gray clay containing crystals of selenite	20	

Laramie beds exposed in clay pit of the Kenmare Hard Coal, Brick and Tile Company.

The Kenmare Hard Coal and Brick Company make use of the Laramie clay at their plant, located two and one-half miles south of Kenmare. Thirty or forty feet are exposed in the face of the pit from which the material is secured. The beds are composed mostly of a gray clay, with some sandy layers and a four foot bed of brown clay, with a thin seam of lignite at the bottom. (Plate III.)

The Laramie is also used by the Mouse River Lignite Coal and Brick Company, whose plant is one mile below Burlington, beside the Soo railroad. Over thirty feet of clay are exposed here, including a four-foot brown layer near the base, which contains many fossil shells. The clay above is filled with many sandstone concretions and included in it are several bands of yellow silicious clay-ironstone.

Morton County.—Although this county lies within the drift covered area, the Laramie appears at the surface in all parts of the district, since the drift is thin and has been removed in many places. Outcrops are found along the Missouri river, which borders the county on the east, along the Cannon Ball and Heart rivers, tributaries of the Missouri from the west, in many buttes and elsewhere.

Along Hailstone creek, in the vicinity of Sims, the following section is exposed:

		Feet.	Inches.
11.	Clay	40	
10.	Lignite	2	
9.	Clay		6
8.	Lignite	2	
7.	Clay	40	
6.	Sandstone, cross-bedded	3	6
5.	Clay	60	
4.	Lignite, impure	4	
3.	Clay	10	
2.	Lignite	7	
1.	Clay	12	

The brick plant at Hebron uses Laramie clay in part, but the white fire clay which is obtained several miles north of town and overlies that obtained from the coal mine, is probably younger than the Laramie. It seems likely that it is Tertiary. The section at the clay pit is as follows:

		Feet.	Inches.
6.	Sand, with carbonaceous clay layers	10	
5.	Limonite		2
4.	Clay, impure, ferruginous, carbonaceous	4	
3.	Clay, sandy, impure, ferruginous		10
2.	Clay, dark colored, with carbonaceous layers more plastic than No. 1, and contains more iron	5	6
1.	Fire clay, white	50	

Stark County.—This county is nearly free from drift, although thin patches occur in the northern and eastern townships and glacial boulders are found as far west as Dickinson. The Laramie beds appear at the surface in all parts of the area and outcrops are numerous. The county is drained by the Heart river and its tributaries, which flow in valleys 50 to 100 feet and more in depth, many of them bordered by terraces. The country back from the streams is flat or quite rolling, with an occasional butte rising several hundred feet above the general level of the plain.

Part of the clay used by the Dickinson Pressed Brick and Fire Clay Company comes from the Laramie formation and part from beds which overlie this and perhaps belong to the Tertiary. The section given below is exposed in the clay pit located directly at the plant and in the bank of the Heart river.

SECTION IN THE CLAY PIT OF THE DICKINSON PRESSED BRICK AND FIRE CLAY COMPANY.

		Feet.
5.	Clay, sandy, yellow	8 to 10
4.	Coal, with some clay	1
3.	Clay, blue	4 to 5
2.	Coal	5
1.	Unexposed to river	5

The Laramie beds are well shown in the bluff which rises abruptly from the river one mile south of the brick plant and at the top of which is located the second clay pit. Only the lower portion of the section, including the Laramie strata, is given here, the remainder being reserved for the discussion of the more recent white fire clays.

SECTION ON THE HEART RIVER, ONE MILE SOUTH OF DICKINSON.

		Feet.
5.	Lignite, impure, and brown carbonaceous shale	1
4.	Clay, becoming sandy in places	8 to 10
3.	Lignite, impure	3
2.	Sand, somewhat argillaceous, with impure iron concretions, unexposed in part	30
1.	Lignite of fair quality, exposed in bed of river	8

The clay used from this locality is obtained from beds lying nearly fifty feet above the foregoing section and it will be described later.

Billings County.—There is probably no better place in the state to study the Laramie formation than in Billings county. The Little Missouri river has cut a valley over 300 feet deep and in this the beds are excellently exposed. The badlands form a belt five to ten miles wide on either side of the river, and here the Laramie clays and sands have been carved into buttes, domes, towers and countless fantastic shapes. In the bare clay slopes one may trace the beds for miles, and the many-colored strata appear with great distinctness. Back from the streams and beyond the badlands the surface is a flat or gently rolling plain. A conspicuous feature of this plain is the numerous buttes which rise from 100 to 400 feet and more above it.

Only a few representative sections showing the character of the Laramie in this county can be given. The first one appears in the bluffs at Medora.

SECTION IN THE BLUFFS OF THE LITTLE MISSOURI AT MEDORA.

		Feet.	Inches.
40.	Shaly sandstone, gray weathering to yellow, finer grained than No. 39. Contains cherty layer	15	
39.	Sandstone, dark-gray, rather soft, coarse-grained, massive; forms vertical escarpment near top of bluff	45	
38	Lignite seam and coaly shale		1 to 4
37.	Clay shale, gray and yellow	9	
36.	Lignite seam		3 to 4
35.	Clay shale		6
34.	Gray, fine-grained, shaly sandstone	6	
33.	Yellow clay shale	1	6
32.	Lignite seam		6
31.	Gray clay shale	1	
30.	Gray, sandy shale	6	
29.	Clay shale, gray	1	6
28.	Chocolate brown clay shale with thin lignite seam	1	

		Feet.	Inches.
27.	Gray clay shale....................................	4	
26.	Soft, shaly sandstone, gray and buff, laminated, fine-grained; in places forms hard sandstone ledge projecting beyond the softer shales above and below....	15	
25.	Gray and yellow clay shales, with some sandy layers..	5	
24.	Chocolate brown clay shale with plant impressions....		[illegible]
23.	Lignite seam.......	1	6
22.	Clay shale, gray and yellow, with some sandy layers and a thin streak of lignite..........................	30	
21.	Sandy shale passing above into a compact, hard, fine-grained gray sandstone. This rock forms a projecting ledge..................	3 to 4	
20.	Gray and yellow clay shale..........................	5	6
19.	Fine-grained sandstone, forming projecting ledge.....	2	
18.	Gray and yellow clay shale..........................	4	6
17.	Gray, fine-grained, sandy shale......................	6	
16.	Lignite streak and chocolate brown shales...........		½
15.	Gray, sandy shale and soft sandstone. In places the sandstone is cemented into hard rock, forming projecting ledge............	7	
14.	Gray clay shale....................................	1	
13.	Chocolate brown shale..............................		8
12.	Lignite seam...................	1	
11.	Gray and yellow clay shale..........................	25	
10.	Chocolate brown shale..............................	2	
9.	Lignite seam................	4	
8.	Chocolate colored clay shale with abundant plant remains, mostly stem impressions..................	1	
7.	Gray clay shale....................................	3	
6.	Sandy shale and fine-grained sandstone.............	16	
5.	Clay shale...............	4	
4.	Sandy clay shale...................................	6	
3.	Gray clay shale....................................	1	
2.	Lignite seam..................	9	
1.	Gray clay shales, not well exposed to river...........	40	

Some of the clays in the above section would undoubtedly be suitable for brick and other clay products.

SENTINEL BUTTE SECTION.

		Feet.	Inches.
29.	Alternating layers of highly calcareous gray clay and very fine-grained, compact, brittle, gray limestone, finely laminated and more or less silicious. Some of the sandstone beds weather into thin laminae, one-sixteenth of an inch thick and less.................	7	
28.	Very calcareous, gray clay, weathering to a greenish color......	18	

		Feet.	Inches.
27.	Gray, hard sandstone	40 to 50	
26.	Gray and yellow, sandy clay	25	
25.	Brown clay and thin seam of lignite	1	6
24.	Gray and yellow, sandy clays	48	
23.	Lignite seam		6
22.	Soft, fine-grained, argillaceous sandstone	12	
21.	Brown and gray clay shale containing many selenite crystals	4	
20.	Soft, fine-grained sandstone	1	
19.	Lignite seam	1	to 18
18.	Chocolate brown clay shale, with carbonized wood	1	
17.	Bluish gray clay	10	
16.	Gray sand, cemented in places into soft sandstone	12	
15.	Not well exposed, but probably clay shale	50	
14.	Lignite seam		2
13.	Gray sandy clay	32	
12.	Gray clay shale with no sand	2	
11.	Lignite seam	6	
10.	Sandy clay shale, colored brown above	5	
9.	Fine, gray sand	4	
8.	Gray, sandy clay shale, containing nodules, similar to No. 6	14	
7.	Finely laminated sand	4	
6.	Gray, sandy clay shale with ferruginous bands	8	
5.	Chocolate brown, sandy clay shales	1	
4.	Gray clay shales with no sand	5	
3.	Sandy, gray clay, containing abundant silicious iron nodules, arranged mostly in bands at certain horizons; these hard nodules project from the surface of the softer clay, and also cap small clay columns	20	
2.	Unexposed, includes some sand	20	
1.	Lignite seam, outcropping in bottom of ravine near the east end of the butte, exposed	20	

Numbers 28 and 29 of the above section are probably Tertiary.

One mile south of Yule, where the river swings against the bluff on the west side, the following section is exposed:

		Feet.	Inches.
14.	Silt and fine sand grading below into gravel. In places this gravel rests on the lignite bed (No. 13)	25 to 35	
13.	Laramie clay	10	
12.	Lignite	10	
11.	Clay and sand	18	
10.	Lignite	2½	
9.	Clay and sand	47	
8.	Lignite	2 to 3	
7.	Clay	3	
6.	Lignite	1 to 1½	

	Feet.	Inches.
5. Clay	1	
4. Lignite		6 to 8
3. Clay and sand	26	
2. Lignite	4	
1. Clay, to river level	40	

Burleigh County.—The Laramie beds, although they underlie the drift over the entire county, have few outcrops except along the Missouri river, on the western border. They appear in the bluff at the east end of the Northern Pacific bridge over the river at Bismarck, where forty to fifty feet of brown and rather sandy, jointed clay are seen above the level of the track.

The Laramie clay from which brick is made at the Wilton plant comes from the large Washburn mine at the same locality. The section as given at the mine shaft is as follows:

	Feet.	Inches.
7. Drift	8	
6. Clay and sand	44	
5. Clay, jointed, brittle	8	
4. Lignite	8 to 13	
3. Clay		6 to 18
2. Lignite		6 to 24
1. Clay, thickness removed	8 to 10	

Number 1 is the material used in the brick plant, and it has been found well suited for the manufacture of clay products.

The clay used at the State brick yard at Bismarck is not Laramie but is mostly a drift clay derived from it, and more or less modified by running water.

McLean County.—McLean county, like Burleigh county, is covered with glacial drift which nearly everywhere conceals from view the Laramie beds. The surface is a gently rolling to rough plain, rather poorly drained in places, and with numerous sloughs or lakes. The clays and sands of the Laramie are exposed in the bluffs of the Missouri river and its tributaries. At the big bend near old Fort Stevenson and about two miles below the mouth of Snake creek the following section appears:

SECTION AT THE BIG BEND OF THE MISSOURI RIVER.

	Feet.	Inches.
38. Drift	30	
37. Clay shale, chocolate brown below, gray above	5	
36. Lignite seam	3	6
35. Clay shale, containing plant impressions	1	6

		Feet	Inches
34.	Fine, argillaceous sand	8	
33.	Gray, laminated clay shale	5	
32.	Lignite seam		3 to 5
31.	Gray clay shale	5	
30.	Sandy, gray clay stained yellow in spots by iron oxide	6	
29.	Brown clay shale with thin lignite partings		6 to 10
28.	Light gray clay, growing sandy above	5	
27.	Gray, sandy clay with ferruginous nodules and yellow limonitic bands	20	
26.	Clay shale, gray and yellow in alternating layers, with thin, yellow, limonitic bands. Contains many *Unios* and gastropods including *Viviparus trochiformis*	4	
25.	Brown and black, brittle, coaly shale	1	
24.	Brown clay shale	1	
23.	Lignite seam		6 to 8
22.	Brown clay shale with plant remains		10
21.	Lignite seam		2 to 3
20.	Clay with abundant plant impressions		2
19.	Fine, argillaceous sand	3	
18.	Gray clay shale, crumbles readily into thin flakes	1	
17.	Thin lignite seam		½
16.	Gray and yellow clay shale in alternating layers; crumbles readily on exposure to the weather. Contains *Unios* and gastropods	4	6
15.	Clay shale, chocolate brown, with fossils similar to those in No. 16	4	
14.	Lignite seam		10
13.	Clay shale, gray, weathers into thin flakes	1	6
12.	Gray and yellow, sandy clay with ferruginous nodules	10	
11.	Lignite seam with some coaly shale		8
10.	Gray clay shale	4	
9.	Lignite seam and brown, carbonaceous clay		2
8.	Gray, sandy clay, stained yellow in spots by iron oxide. Contains very many sandy, ferruginous nodules, distributed mostly in bands. The nodules stand out on the surface and fragments of them cover the slope. Also contains large sandstone concretions and lenses	31	
7.	Gray and yellow argillaceous sand	4	
6.	Gray clay, with no sand, and containing nodules of iron oxide	1	
5.	Lignite seam	3	
4.	Gray clay shale	1	
3.	Lignite seam, entire thickness not exposed, but at least	4	
2.	Sandy clay shale	10	
1.	Unexposed to river	15	

TERTIARY.

As was stated on a previous page, the Fort Union formation, which belongs to the Tertiary, is here included in the Laramie, since the beds have not yet been differentiated in North Dakota

The white fire clays which contain little lignite and overlie the Laramie formation are believed to belong to the Tertiary. These cover a large area lying between the Missouri and Little Missouri rivers, and extending from the Indian Reservation, north of the latter stream, south to the divide north of the North Fork of the Cannon Ball river, and from a few miles east of Hebron west to the divide separating the streams flowing into the Missouri from those flowing in the opposite direction into the Little Missouri.

These white clays, which cover an area of approximately 4,000 square miles, lie at an elevation of from 2,450 to 2,600 feet above sea level, and are confined to the tops of the higher ridges and divides. They have a maximum thickness of about 150 feet.

The fire clays are remarkably uniform over the entire area, not only in appearance but in chemical composition, as shown by analyses of samples from many different localities. Their white color makes them conspicuous wherever they are exposed.

These clays are well shown in the clay pit of the Dickinson Pressed Brick and Fire Clay Company, one mile south of their plant, where the following section occurs, a portion of it having been given on a previous page:

SECTION ON THE HEART RIVER, ONE MILE SOUTH OF DICKINSON.

		Feet.
10.	Fire clay, white, sandy, coarse-grained. Is composed chiefly of quartz sand, with some white kaolin clay, which coats the sand grains, fills the intersticies and gives the beds their white color	7 to 10
9.	Pottery clay, very fine-grained and pure, light gray to white....	1 to 2
8.	Clay, blue, fine-grained, plastic, grading above into No. 9.......	5 to 6
7.	Sand, gray, fine-grained, slightly argillaceous, shows cross-lamination..........	45
6.	Clay, sandy	4
5.	Lignite, impure, and brown, carbonaceous shale..........	1
4.	Clay, becoming sandy in places..........	8 to 10
3.	Lignite, impure	3
2.	Sand, somewhat argillaceous, with impure iron concretions, unexposed in part	30
1.	Lignite, of fair quality, exposed in bed of river..........	8

Numbers 1 to 5 are Laramie or Fort Union, while numbers 6 to 10 are thought to be Tertiary, although the scarcity of fossils

Tertiary clays exposed in Goodman Valley, in northwestern Mercer county. Sides of the butte are carved by rain erosion.

Butte five miles northwest of Sandcreek Postoffice. showing sand and clay beds of the Tertiary.

makes the determination of their age difficult, and it is still in doubt. Number 10 is used in the manufacture of fire brick and other refractory products. Number 9 is an excellent pottery clay which has been made into a variety of clay wares in several eastern potteries. Number 8 is suitable for common brick and sewer pipe, while 7 has been used for common brick. (See Plate IX.)

At the clay pit of the Hebron plant at least fifty feet of fire clay are exposed, very similar in appearance to that at Dickinson.

The most southern point that the high grade white clays were observed was in Black Butte, about twenty-five miles south and a little west of Dickinson. They are finely exposed on Antelope creek, a tributary of the Heart; on the wagon road between Dickinson and Gladstone and north of the railroad; in several low hills or knolls about two miles northeast of Gladstone. The same clays appear near the base of the Killdeer mountains and they occur on the north side of the Little Missouri river, on the Fort Berthold Indian Reservation.

The position of these white fire clays on the top of the ridges and divides and their absence from the lower portions of the area indicates that they have undergone extensive erosion. They undoubtedly at one time covered the entire region within which their outcrops are found, having been laid down on top of the Laramie formation, probably in a large lake or lakes. As previously stated, these beds contain almost no lignite, showing that during their deposition conditions were not favorable for the formation of coal.

Calcareous Sandstone.—Overlying the beds described above there are several hundred feet of light gray, calcareous sandstone. This is well exposed in White or Chalk Butte, near Sandcreek post office in southern Billings county, in the Killdeer mountains and at other points. The vertical cliffs on the south side of the Killdeers are formed of this white sandstone. Some of the ledges are thin-bedded and weather very irregularly, forming a rough and pitted surface. At the top there is a thickness of thirty to forty feet of soft sandstone which crumbles readily in the hand and is in layers two to four inches thick. The total thickness of these beds is 230 feet. (Plate V.)

In the calcareous sandstone of Chalk Butte, about two miles east of Sandcreek, the skull of an extinct species of ruminant was found. This was identified by Mr. J. W. Gidley, of the Smithsonian Institution as *Eporeodon major* (?), which is found in the upper Oreodon beds of the Oligocene age. This would indicate that the

beds belong to this division of the Tertiary and are therefore to to be correlated with the light colored strata occurring in the Slim Buttes and Short Pine Hills of South Dakota, and the Long Pine Hills of Montana.

To the same horizon have also been referred the marl and limestone beds found on top of Sentinel Butte and having a thickness of twenty-five feet.

PLEISTOCENE.

Drift.—The larger part of North Dakota is covered to a greater or less depth by a peculiar deposit known as glacial drift. It is very different in appearance and origin from the geological formations previously described and forms a mantle which buries from view the older rocks. The drift is composed of clay, sand, gravel and boulders mingled together to form a heterogeneous deposit. The chief constituent is a stiff blue or gray clay through which are scattered numerous pebbles and boulders of granite or other igneous rock. It is commonly known as boulder clay or till and nearly all of the boulders and smaller rocks differ from the underlying strata, having been transported from distant localities where ledges of such rock occur. Another peculiarity of the pebbles and boulders of the drift is that many are smoothed, polished or scratched on one or more sides.

The drift was formed by a continental ice sheet or glacier which once covered the northern part of North America just as Greenland and the Antarctic regions are today covered by vast ice caps. This glacier extended as far south as Long Island, the Ohio river at Cincinnati and the Missouri river, in Missouri. It entered eastern Kansas and Nebraska, South Dakota, and covered all of North Dakota except several counties in the southwestern corner. The drift represents the materials that were gathered up by the ice sheet as it advanced over the land, were accumulated beneath the ice, and were left behind when it melted. The foreign boulders and pebbles of the drift have been transported from the north and left, often hundred of miles from their source. Most of the granite boulders of this state have been brought from Canada in this manner. The polished and scratched faces found on so many of them, particularly on the smaller ones, were formed when the rock fragments were frozen in the bottom of the ice and were carried along between the heavy ice sheet and its rocky bed, wearing down, smoothing and striating both the pebbles and the rock bed over which they passed.

It is known that there are five separate and distinct sheets of drift produced by different ice invasions, but not more than two of these, and probably only one, occurs in North Dakota. Between the time of deposition of the various sheets the ice retreated for a time, and these interglacial intervals are marked by vegetable accumulations representing ancient forests and soils, often many feet in thickness, and by heavy deposits of gravel and sand laid down by streams flowing from the melting ice.

Considerably more than half of North Dakota is covered by the youngest of the drift sheets, the Wisconsin, whose border is marked by a conspicuous belt of irregular hills and hollows ten to fifteen miles wide, constituting the Altamont moraine, as it is called. This was formed along the edge of the ice where it remained stationery for a time, the rock debris carried by the glacier being accumulated and heaped up into the morainal drift hills, which are often dotted with numerous large boulders. This moraine has been traced across the state from north to south; it traverses Ward county from northwest to southeast, about thirty-five miles west of Minot, keeps the same direction through McLean county, turns south through eastern Burleigh county, crosses northeastern Emmons and after making a loop to the east into Logan and McIntosh counties, again enters the southeastern corner of Emmons, whence it continues into South Dakota. The Northern Pacific crosses the Altamont moraine between Driscoll and Sterling.

Lying west of the moraine is an older drift sheet which has been regarded as the Kansan. There is, however, much reason to doubt whether it is as old as the Kansan, since it has few or none of the characteristics of that drift sheet as found in other states, having every appearance of being much more recent. It is quite fresh and unweathered, is light gray in color where exposed in railroad cuts and elsewhere, and its surface has undergone very little erosion, being poorly drained in many places and containing many lakes. The pebbles of granite and other igneous rock are noticeably fresh, rotted and decomposed pebbles being very rare. In all these respects this extra-morainal drift is strikingly different from the typical Kansan. It is possible, however, that the difference is due to the semi-arid climate of the region, the weathering effect on the drift of the dry atmosphere being much less than farther south in Iowa, Kansas, and other states where there is much more moisture.

Yet it is quite probable that this drift is younger than the Kansan, as it has every appearance of being, and it is perhaps an earlier Wisconsin drift than that occurring within the Altamont moraine. More work will be required, however, before the age of this extramorainal drift can be fully determined.

This glacial deposit is not bordered by any terminal moraine, but thins out toward the edge so that the boundary is not well defined. So far as our present knowledge goes this older drift sheet extends from thirty to fifty miles or more west and south of the Missouri river. Over much of the area beyond the river it is thin and has modified but slightly the preglacial topography. Billings, Bowman, Hettinger and Stark counties are practically free from drift, although some boulders occur within their borders and perhaps thin patches of drift may be present.

The thickness of these glacial deposits varies within wide limits, being all the way from a few feet to several hundred feet. In the eastern part of the state it is shown by wells to be commonly from 200 to 300 feet thick, and it is probable that these figures also apply to the central part of the region. Wells pass through 220 feet of drift at Fargo, 250 at Casselton, 310 feet near Grandin and Kelso, and 298 feet at Grafton. The Grand Forks well penetrated 380 feet of drift and lacustrine deposits before reaching bed rock.

Much of the Wisconsin drift is not suitable for brick or other clay products on account of the large amount of lime it contains This is present in the form of pebbles and boulders scattered through the clay, as concretions, and disseminated widely through the drift in fine particles. Unless the material can be largely freed from this lime it cannot be successfully used for clay wares. In some places this separation has gone on in nature, and on the slopes of ravines and valleys or on the bottom of shallow depressions the wash material from the drift has accumulated to the depth of several feet and is fairly free from lime.

At many localities in other states, where the Wisconsin drift is used, the injurious lime impurities are removed by grinding, screening and washing the clay and thus rendering it suitable for brick, tile and other ware.

Many areas can doubtless be found in this state where the pebbles and lime concretions have been largely removed. Such areas may be looked for toward the base of slopes bordering ravines, coulees or valleys, where the finer particles of the drift have been gradu-

ally washed down to the lower levels and deposited, leaving behind the coarser materials, including the gravel and lime concretions.

The Wisconsin drift is used for the manufacture of brick at Bismarck, Rolla and Richardton.

Lacustrine Deposits.—Deposits laid down in large Pleistocene lakes cover extensive areas in North Dakota and are of value as a source of brick clay. Nearly one-half of the plants in the state use these clays. The largest of these bodies of water was Lake Agassiz, which occupied the Red River Valley and extended north into Manitoba, with an area of 110,000 square miles, or more than the combined area of the Great Lakes. The lake was brought into existence when the continental ice sheet, during its retreat northward, gradually uncovered the broad depression known as the Red River Valley, and formed an immense dam of ice at the north which prevented the drainage from the melting glacier from finding an outlet in that direction. As the ice retreated the lake was extended in that dirction and continued to increase in size until its maximum area was attained.

The rivers emptying into Lake Agassiz carried large quantities of sediment, which were distributed by the waves and currents and settled to the bottom to form the sandy clay or loam constituting the lacustrine deposit. This lake silt overlies the glacial drift and is in places seventy feet thick, though it is commonly thirty to fifty feet and less. It consists of rock flour, ground and pulverized by the ice sheet, and mixed with more or less fine sand.

The lacustrine deposits of Lake Agassiz occupy the larger part of the six Red River Valley counties, namely, Richland, Cass, Traill, Grand Forks, Walsh and Pembina. There are eight clay plants that are making use of this lake silt, including four at Grand Forks, two at Fargo and one each at Drayton and Abercrombie.

Another and much smaller glacial lake, known as Lake Souris, existed south and west of the Turtle Mountains. It extended west and south as far as Minot and Velva, east as far as Rugby and north across the international boundary into Manitoba. The deposits laid down in this lake occupy the greater portion of Bottineau and McHenry, and adjoining portions of Rolette, Pierce and Ward counties. The brick plant three miles north of Omemee uses eight to nine feet of gray and rather sandy clay lying under eighteen inches of black soil, which is scraped off and thrown aside. Under the clay is a fine sand which is used in the molds.

Alluvial Clays.—The most recent of the clay deposits of the state is the alluvium, found along many of the streams, particularly the Missouri. The alluvium occurs on the lowlands or flood plains, forming the bottoms of the valleys and is seldom more than twenty to thirty feet above the river level. The deposit consists of sand or clay, or a mixture of the two, and represents the sediment laid down by the streams in time of flood. All of the important rivers of the state have developed flood plains varying in width from a fraction of a mile to several miles and formed of alluvium, which constitutes the rich soil of these bottom lands.

This alluvial clay is suitable for common brick and other products and is used at Williston, Minot, Mandan and Hillsboro.

PART III

ECONOMIC GEOLOGY OF NORTH DAKOTA CLAYS

BY

E. J. BABCOCK AND C. H. CLAPP

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CONTENTS.

CHAPTER V.

GENERAL DESCRIPTION AND DISTRIBUTION OF NORTH DAKOTA CLAYS.

The clays of North Dakota are found in the more recent geological formations. Most of them belong either to the Cretaceous, the Laramie, which is a transition period between the Cretaceous and Tertiary, and the Tertiary. Probably some of the clay horizons which have been considered Laramie in age are better referred to the lower Tertiary. The mantle of glacial drift which covers most of the state also furnishes clay of a poorer quality. Some of our best brick clays, and those utilized most extensively, are those deposited in old glacial lakes, such as Lake Agassiz. The alluvium of the flood plains and terraces of our modern rivers furnish good common brick clay. The clays of the state are thus all young in a geological sense, being either Cretaceous or more recent.

The Cretaceous clays of the Benton, Niobrara and Pierre horizons, underlie the east central part of the state, extending in a belt north and south. Outcrops are few, the strata being covered with a deep layer of drift. The Benton and Niobrara are best exposed in the valleys made by the rivers in the Pembina Mountains. Records of these formations are also found in well sections. The Pierre overlies the Benton and Niobrara and outcrops throughout the district, the best exposures being found in the cut banks of the rivers, notably the Pembina, Sheyenne and James rivers. The entire western half of the state is directly underlain by the coal-bearing beds, which are partly Laramie and partly Fort Union, and consist largely of sands and clays. The Laramie, wherever found, is covered with glacial drift execpt in the southwestern corner of the state. But outcrops are numerous, the strata being exposed in valleys and buttes throughout the area. In the neighborhood of Dickinson, near the tops of the buttes and on the divides between the rivers, white plastic clays are found. These are more refractory and purer than the underlying clays and shales associated with the coal. These upper clays are probably Tertiary in age, and will be so designated

in the following descriptions. Clays of glacial origin are found throughout the state, the best of which are suitable for brick, being found below the soil of the gently rolling prairies. In the Red River Valley good brick clays of lacustrine origin occur. The terraces of all the larger streams also furnish alluvial clay suitable for the manufacture of common brick.

The range in the character of the clays is very great. Many of the glacial, lacustrine and terrace clays furnish a good common brick clay, since they are moderately plastic and easy burning. They seldom burn red, so that practically all the common brick in the state is buff, pink or light red; but some are the deep brick-red, so common in the east. Some of the lower of the Cretaceous clays and some of those associated with the lignite furnish material suitable for the manufacture, by the dry press or stiff mud process, of higher grade bricks. Hollow brick, drain tile, and other structural material can also be manufactured from some of these clays. They usually contain enough iron to burn red or cream, or occasionally iron in the form of ochre is found in the neighborhood, so that it can be mixed with them at a small expense. The clays then will burn easily and to a red color. The white, plastic clays in the Dickinson region furnish material suitable for stoneware. Some of these beds are more refractory and purer and burn white, making them good pottery clays. Some layers are rich in silica, and yet contain enough clay substances to be plastic and strong after burning, these furnish fire clays often of the highest grade. There are, therefore, in the state clays varying from common brick clay to the highest grade of fire and pottery clays.

North Dakota, although not at present a clay producing state of great importance, will undoubtedly take front rank when the demand for clay industries has grown stronger with the development of the northwest. It is well adapted to the industry, for fuel is cheap and clay deposits of many grades are found in different parts of the state. The clay is also easily mined, it is usually soft, crushes readily and lies in undisturbed horizontal beds.

CHAPTER VI.

CRETACEOUS CLAYS.

A description of the geological and geographical occurrence of the clays of the different horizons has already been given in Part II, so that the following pages will be devoted chiefly to a detailed description of the deposits, to the results of the physical and chemical tests, and to suggestions as to the uses to which the various clays may be put.

Benton.—The Benton shales, though probably underlying much of the central part of the state, outcrop only in the Pembina Mountain region, although they have been reported by Upham in the valley of the Sheyenne, near Lisbon. In the Pembina region they are exposed in the deep valleys of the Tongue, Little Pembina and Pembina rivers. About 150 feet of a green and blue clay shale exposed on the Pembina is classified as Benton.

One of the best outcrops is at Mayo, five and one-half miles west of Walhalla, in the deep valley of the Pembina river. The shales are here used by the Mayo Brick and Tile Company, and were studied in detail. The outcrop is on section 33, T. 57, R. 163, and is opposite the junction of the Little Pembina with the Pembina.

About 150 feet of blue and black shales are shown here, the lower 60 feet of which are not well exposed, being covered by a slide from above. The main deposit is quite uniform. It consists of a very fissile clay shale, soft, easily mined and prepared, and slaking readily. It is of a gray color when dried, is almost black when freshly exposed, and contains many dark carbonaceous particles. Small ferruginous concretions are also abundant. Pyrite is found in small quantities, being reduced by the abundant carbonaceous material. In the lower part of the beds some of the carbonaceous matter has been distilled, and the clay has a strong odor of petroleum. The clay is fine grained, with very little grit, but the concretions are more sandy. It would be almost impossible to eliminate these small concretions in crushing, but they may be easily crushed and mixed with the clay.

The unweathered shale, when crushed finely, requires a great deal of water, as much as 46.3 per cent. being necessary to bring it up to its maximum plasticity, which is only moderate. The clay is some-

what sticky. It can, however, be greatly impoved by weathering. The shrinkage for such a high absorption is low, being only 5.7 per cent. A tensile strength of 108 pounds per square inch was obtained from the dry unburned clay.

The burning tests were as follows:

	Cone 010	Cone 05	Cone 03	Cone 01	Cone 5
Fire shrinkage	2.3 per ct.	4.3 per ct.	5.5 per ct.	7.3 per ct.	9.3 per ct,
Absorption		21.8 per ct.	18.9 per ct.	15.8 per cc.	8.5 per ct.
Color	orange red	orange red	red	red brown	dark brown

The bricklets became steel hard when burned to cone 01, and were strong. Incipient fusion occurred at cone 5, and vitrification at cone 8, but the clay did not become viscous below cone 14.

A chemical analysis shows the clay (No. 5901) to have the following composition:

	Per Cent.
Silica	69.90
Ferric oxide	2.32
Alumina	10.66
Lime	1.04
Magnesia	2.10
Volatile matter	6.09

A weathered sample (No. 5905) of the slide deposit covering more or less the main deposit, was also tested. This weathered shale is coated and seamed more or less by yellowish and white colored material. It consists of gypsum, part of which has been reduced by the carbonaceous material to sulphur, and gives considerable trouble in burning. The material of this was evidently deposited near the top of the Benton, which is higher in lime and sulphur (containing thin layers of gypsum crystals) than the lower part, and is consequently a much less desirable clay.

It is a fine-grained clay with little grit, and free from concretions, although containing gypsum crystals. It it a dark olive gray in color. It slaked very easily, and with 30.4 per cent. of tempering water became very plastic but rather sticky. It had a high air shrinkage of 8.0 per cent., but dried without cracking, possibly due to the large tensile strength of 192 pounds.

Great trouble was experienced in burning; the clay fused incipiently at low temperatures, before all the sulphur was driven off. The remaining sulphur reduced the iron so that all the bricks had a black color, as have the stiff mud bricks made from it on a large scale. As the clay approaches vitrification the imprisoned sulphur

dioxide bloats the clay and makes it valueless. Probably by very careful burning, keeping the clay at low heat for a long time, so as to eliminate all the sulphur, it could be burned successfully. As it is, pressed brick, hollow brick, and drain tile can only be properly manufactured, the thickness through which the sulphur gases penetrate being small. The results of the laboratory burning tests were:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	1.7 per ct.	5.5 per ct.	6.4 per ct.	failed by warping
Color	light orange	light red	light red	red brown
Absorption	13.4 per ct.	6.4 per ct.	5.8 per ct.	2.4 per ct.

The clay becomes incipiently fused at cone 06, was vitrified at cone 4, and became viscous at cone 11. No chemical analysis was made of the sample, but it is evidently lower in iron and higher in lime than the other unweathered shale, due to the fact that it is from a higher horizon. The great difference in plasticity between the two samples is interesting, and shows the great influence of weathering.

C. P. Berkey[1], who has examined this property in the interests of its owner, H. A. Mayo, has published two of the following analyses, and one made by him was furnished by Mr. Mayo:

	(1) Per Cent.	(2) Per Cent.	(3) Per Cent.
Silica	61.03	61.52	67.55
Alumina	22.07	18.65	12.40
Ferric oxide	6.53	4.90	5.86
Lime	0.97	0.75	1.74
Magnesia	0.51	1.32	trace
Water	7.92	8.80	10.45

Sample No. 1 was from near the level of the plant, about 75 feet above the river, while No. 3 was near the top of the Benton, and sample No. 2 half way between. It is interesting to note the decrease in alumina and the increase in lime, upwards.

The clay near the base of the Benton is preferable. It is suitable for the manufacture of red front pressed brick, and if ground very fine or weathered so as to make it sufficiently plastic it may be worked by the stiff mud machine for making bricks, certain grades of hollow ware and tile.

At present the deposit is not on the railroad, the nearest point being the Walhalla branch, about five miles east. A track could be laid down the valley of the Pembina to meet this branch, a distance

[1]American Geologist, March, 1905, p. 151.

of six or seven miles. The building of this track is contemplated, and when built should open up a good market for the plant already established.

Niobrara.—The Niobrara formation which overlies the Benton and is not sharply differentiated from it, outcrops most extensively in the Pembina Mountain region, and forms a considerable part of the strata exposed by the Tongue, Little Pembina and Pembina rivers. It does not, however, contain any shale valuable as a clay. This is due to the high lime content, varying from 20 to 75 per cent. calcium carbonate. This makes certain beds of it valuable for the manufacture of natural cement, but destroys all its usefulness as a clay.

The main part of the strata classified as Niobrara, known as "cement rock," is rather hard and massive, breaking out in large pieces. It is of a gray color, and contains white specks of carbonate of lime. The uppermost part of the Niobrara is a chalky formation, often carrying gypsum, iron concretions and thin layers impregnated with alum. The cement shales, which are high in lime, burn white at low temperatures, and those which are much lower in lime cream colored, but none of these are of use in the manufacture of clay products.

A calcareous clay, which is probably Niobrara, also outcrops in the valley of the Sheyenne near Valley City. It underlies the peculiar horizon of banded black and white shale, which marks the top of the Niobrara or base of the Pierre in the Pembina Mountains. The Niobrara at Valley City (No. 5503) is a massive shale, breaking into large fragments. It has a fine grained body, but contains some very fine sand. The color is a medium gray, which weathers to a light cream.

This calcareous clay was tested, but was proven worthless. It requires 30.3 per cent. of water for the best plasticity, which is good. It has an air shrinkage of 6.4 per cent. and a tensile strength of 131 pounds. The burning tests were as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	2.4 per ct.	2.4 per ct.	2.9 per ct.	2.8 per ct.
Color	gray	pale gray	pale gray	pale gray
Absorption	27.5 per ct.	27.0 per ct.	27.4 per ct.	28.7 per ct.

The bricklets were all badly cracked. Incipient fusion did not occur until cone 2, and rapidly became viscous at cone 6.

A chemical analysis shows the following composition:

	Per Cent.
Silica	29.27
Ferric oxide	3.82
Alumina	10.74
Lime	26.68
Magnesia	1.53
Loss on ignition	23.59

Such a clay is valueless, the lime content being too high. The same is probably true of all the Niobrara clays until they become high enough in lime to be useful as cement.

Pierre.—The Pierre forms the uppermost horizon of the Cretaceous shales, and underlies the entire east central part of the state, forming a belt probably a hundred miles wide north and south. It is for the most part covered with a thick deposit of glacial drift, so that it is only exposed where the larger streams have cut down into it. The best outcrops occur along the Pembina, Little Pembina and Tongue rivers, where these have worked back into the escarpment bordering the Red River Valley. Outcrops are also found on the Park, Forest and Turtle rivers. The Sheyenne and James rivers have also croded through or into the Pierre shales. Along the Sheyenne they outcrop at many points from its source to below Valley City. Good exposures occur along the James and Pipestem creek near Jamestown and a few miles north. The Pierre thus not only underlies the central part of the state, but is exposed in many places, and is thus available for use.

In general the Pierre is quite uniform throughout its whole extent. It consists of a dark gray, blue, or black carbonaceous shale. It is fissile and weathers easily into thin plates. The shale is fine grained but contains a little very fine sand. It also contains many small iron concretions which weather out and are seen scattered around at the base of an outcrop. This iron stains the clay brownish when weathered. Though high in iron, no samples of the Pierre are high enough in lime to give any effervescence with acid. Just what percentage of lime is present is impossible to say, as all the samples were collected too late for a chemical analysis, but it is safe to say that it is low.

About 300 feet of Pierre shales are exposed in the Pembina Mountain region. The lower part consists of a very fissile, dark gray to black carbonaceous shale. It weathers out into very thin small flakes. Scattered along the outcrop are seen many small iron nodules.

An examination of the shales exposed along the main Pembina

river for two or three miles north of Mayo was made and a sample, (No. 5906), was collected about two miles north of the Mayo brick plant, and fifty feet above the base of the Pierre.

The shale here is very fine grained, with but little grit. It contains, however, a few small pyrite concretions, which weather to limonite. The clay is not very hard and could be easily mined and crushed. It does not slake so readily as the Benton, a piece one inch in diameter took two days to slake completely when immersed in water. It required 34.0 per cent. of water to temper it to its maximum plasticity, which was good but very sticky. The air shrinkage was 8.7 per cent., and the tensile strength 94 pounds. In spite of its high shrinkage it did not crack in drying, except for a few small cracks on the surface.

The burning tests were as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	1.5 per ct.	5.9 per ct.	5.0 per ct.	failed by warping
Color	pink	light red	light red	red brown
Absorption	17.5 per ct.	9.4 per ct.	9.7 per ct.	4.0 per ct.

The sulphur present in the pyrite caused all the brick to have a black core, and was also the reason of the failure of the bricklet burned to cone 01. Because the cones tested for fusibility were so small that the sulphur was completely eliminated, and the iron oxidized to a ferric condition, incipient fusion took place at cone 05, but vitrification not until cone 7, and viscosity at cone 14.

No chemical analysis was made of this sample. Although this particular sample was so high in sulphur as to be practically worthless for any ware manufactured by the stiff-mud process, good red dry press brick could be made. Then, too, the sample which was taken directly from the outcrop does not represent the best grade of shales in the neighborhood.

A deposit of clay near Olga is described by E. J. Babcock[1] as a fine white clay of slightly acid taste two to three feet in thickness. This is probably in the Pierre horizon, but higher than the beds exposed along the Pembina, being overlain and underlain by black carbonaceous clay shale. It stands a high temperature and burns to a slightly pinkish tint. An analysis shows the following composition:

	Per Cent.
Silica	50.45
Alumina	17.57
Ferric oxide	2.80

[1]E. J. Babcock: Clays of Economic Value in North Dakota, p. 16.

	Per Cent.
Lime	0.25
Magnesia	1.79
Potash	0.07
Soda	0.86
Water and volatile matter	22.55
Other matter	3.66

The clay could be used for stoneware and as a low refractory clay.

The Pierre shales at Valley City belong to the lowest horizon directly overlying the Niobrara. The sample tested was taken from the cut on the Soo railroad about a mile east of the town. The section here shows eight to ten feet of dark, carbonaceous, highly ferruginous shale which weathers easily into thin flakes. This is overlain by a couple of feet of drift and underlain by a layer three to four feet thick of black, white and red banded shale, which seems to mark the base of the Pierre. Below this is the gray, calcareous shale which is probably best placed in the Niobrara.

The sample of the Pierre (No. 5502) was a very smooth plastic clay, but with a good deal of very fine sand. It also contained many ferruginous concretions and considerable carbonaceous material but no lime. It slaked readily, but required 44.4 per cent. of tempering water, the resulting mixture being plastic but sticky. The air shrinkage was excessive, being 14.0 per cent., so that the briquettes for tensile strength as well as the bricklets were much cracked. When the bricklets were placed in the furnace they swelled and cracked badly at a temperature less than cone 010. Such a clay as this is, of course, of no value.

The Pierre shales outcrop along both sides of the James river and Pipestone creek valleys north of Jamestown, although for the greater part they are covered by the slide material and glacial drift. The exact thickness of the beds has not been accurately determined, but is probably at least 100 feet. The elevation of the James river at Jamestown is nearly 200 feet higher than the Sheyenne at Valley City, and the Pierre shales exposed along the James are, therefore, of a higher horizon than those at Valley City, the beds being nearly horizontal.

An outcrop on the east bank of the river one and a quarter miles north of the railroad station at Jamestown was examined. There are exposed here about ten feet of black, fissile clay shale stained with iron, some of the layers containing many concretions. The shales are compact and hard on drying, but are soft in the bank and

can be easily mined. They weather easily to a plastic clay. The texture is fine with little or no grit. As a rule the iron concretions are not numerous, they are small, and are limonite and not pyrite. A sample from here (No. 6302) required 45.6 per cent of tempering water for its best plasticity, which was good. The tensile strength was 89 pounds, the air shrinkage 5.3 per cent., and the briquettes and bricklets dried without cracking. The table following shows the burning tests:

	Cone 010	Cone 05	Cone 03	Cone 01	Cone 5
Fire shrinkage	1.0 per ct.	4.0 per ct.	4.5 per ct.	5.8 per ct.	6.8 per ct.
Color	red orange	orange	orange red	red	brown
Absorption		26.2 per ct.	24.2 per ct.	21.1 per ct.	19.8 per ct.

Incipient fusion occurred at cone 7, vitrification at cone 15, and viscosity at cone 20. The bricklets burned to a strong body and became steel hard at cone 5. This shale is well adapted to the manufacture of red dry-pressed and stiff-mud brick and possibly paving brick or the ordinary hollow structural material, as it can be vitrified with low shrinkage and with no fear of the ware becoming viscous.

This last sample was by far the best of the Pierre shales tested. In a very general way it may be stated that near the base they are useless, but grow better above, so that in the upper part the clay is of a good quality for red brick.

CHAPTER VII.

LARAMIE CLAYS.

Almost the entire western half of the state is underlain by strata which have been referred to the Laramie, but undoubtedly some of them are Tertiary in age (Fort Union). Just where the dividing line between the Laramie and Tertiary occurs is doubtful and can only be determined by paleontological evidence. But lithologically the so-called Laramie formation may be divided into three parts. At the bottom is a great series of beds consisting of impure, low grade clays, sands, many of them somewhat calcareous, and lignite. Above there is a horizon not more than 150 feet thick in which occur the high grade, light burning, more refractory clays, although some of these are highly calcareous and fuse at very low temperatures. No lignite of any importance exists in this horizon. Overlying these clays are some 300 or 400 feet of sand, part of which is cemented by a calcareous cement into a firm sandstone. The coal-bearing beds of the lower division are thought to belong to the Laramie and Fort Union, but the other two formations are probably Tertiary. The marked difference in character, the finding of the skull of an Oligocene mammal in these beds at Sandcreek, and the comparison with known Tertiary and Laramie beds outside the state are reasons for placing these beds at least provisionally in the Tertiary, and they will be so considered in the following descriptions.

The Laramie and Fort Union cover a large area and outcrop wherever erosion has progressed far. The eastern boundary, as shown on the geological map, is marked by a line running southeast from the northwestern corner of Bottineau county to the western part of Wells county, and from there due south along the eastern boundary of Emmons county to South Dakota. The lowest elevation of the Laramie is from 1,500 to 1,600 feet above sea level on its eastern boundary, to 1,350 feet or lower at Medora, a well at this place 941 feet in depth having failed to penetrate the coal measures. It would thus seem that the beds were laid down in a basin which covered the western part of the state. The highest elevation that the coal measures attain, where they are overlain by the white clays, is about 2,450 feet above sea level. In the extreme western part of the

state workable coal seams are found at an elevation of at least 2,800 feet (the 6-foot coal seam noted by Dr. A. G. Leonard in Sentinel Butte). In eastern Montana, however, the lignite beds continue into the known Tertiary (Fort Union) beds without any break, so that it is possible that some of these higher coal seams along the western boundary of the state are Tertiary in age.

Overlying the coal-bearing Laramie, and extending as far west as the divide of the Little Missouri, are a series of clay beds some of which are of high grade character. These have a thickness of form 50 or less to 150 feet, and occur at elevations between 2,450 and 2,600 feet above sea level. These elevations are seldom met with except in the buttes and divides, and it is there that one may expect to find these clays. Extending 300 to 500 feet above these beds is a great thickness of sand. This has been locally hardened to a sandstone either by a calcareous, ferruginous or silicious cement, and forms the protecting ledges of most of the high buttes. There is a marked difference between the two upper series of Tertiary clays and those of the Laramie. For this reason they are discussed separately.

The Laramie clays are in a general way of much poorer quality than the Tertiary clays. The beds associated with the lignite vary from a coarse sand to fine-grained clays. They are not consolidated, although the sand may be locally hardened, but are soft and easily worked. Sand may underlie the lignite as well as clay. Clay usually overlies the lignite, but not always. The clay beds also occur interstratified with the sand, even when no coal is present.

In texture the clays vary from coarse sandy clays to fine-grained ones. As a rule they consist of a very fine-grained clay body, and considerable fine sand. Many of the clays contain ferruginous concretions and all are carbonaceous. Lime is also common, usually over two per cent. being present. Carbon is the chief coloring agent and the colors are usually a dark gray. These clays are soft and compact, sometimes somewhat shaly and laminated, and easily mined and prepared.

The amount of tempering water to develop the maximum plasticity varies from 20.6 per cent. to 42.7 per cent. The fine-grained clays require the most water, while those which require the least contain larger amounts of fine sand. The average amount is 29.1 per cent. The resulting plasticity is generally good. Some of the sandy ones have only a moderate plasticity, but others develop a very good plasticity. The air shrinkage is high, varying from 2.5 per

cent. to 11.6 per cent., the average being 6.3 per cent. Although they have a good tensile strength, from 58 to 339 pounds with an average of 149 pounds, most of the clays check somewhat on drying, and this great difficulty is nearly always met with when these clays are worked by a plastic process.

Most of the clays contain considerable iron, burning usually to a red shade. Some, however, which are high in lime, burn to a buff or orange color. The fire shrinkage is nearly always high and many of the clays fail by cracking or warping at very low temperatures. They are of low fusibility, the most refractory sample becoming viscous at cone 11. The majority of them have a considerable range between incipient fusion and viscosity, but the sandy and highly calcareous ones have a range of only four or five cone numbers. Some can be burned dense, but the large fire shrinkage which takes place when they are thus burned usually causes the clay to crack badly.

Several samples of clay from the Laramie were collected around Williston, where the beds are exposed along the Missouri and Muddy rivers and Stony creek. The best outcrops occur south and east of town. The bluffs are mostly sand and sandy clay, and contain three seams of coal which vary in thickness from five to ten feet. Associated with the coal and usually over it is a clay shale. This averages about four feet thick and grades upward into a much more sandy clay. The clays are plastic but contain more or less fine sand. They are usually of a bluish gray color with but little iron staining. Those in the neighborhood of Williston all seem to be calcareous.

Above the 9-foot coal seam worked at the Continental mine, three miles east of town, is a strong compact clay shale, (No. 5002). It is a fairly fine, uniform grained, smooth clay with but little grittiness. It is free from iron stains, being of a grayish color, but is somewhat calcareous. The material is quite strong and of medium hardness, but slakes readily. It could be mined and prepared easily.

This clay required 42.7 per cent. tempering water, and the plasticity developed was good, but the clay was very sticky. The air shrinkage was 11.6 per cent., and although the clay checked a little, it was not serious. The tensile strength was 174 pounds. The clay was warped and cracked badly when burned to or above cone 05 on account of sulphur, but the bricklet burned to cone 010 was a good red color and strong, with a fire shrinkage of 1.7 per cent. and an absorption of 16.2 per cent. The cones tested for fusibility were

incipiently fused at cone 07, vitrified at cone 04 and viscous at cone 4. The extreme shrinkage of this clay would prohibit its use alone for anything. The sulphur is most detrimental and would give considerable trouble in burning.

Another clay associated with coal, about three miles southeast of Williston, showed about the same physical properties as the one given above. It cracked more in drying and on burning even to cone 010 it swelled and cracked very badly. A sample (No. 5007) from between the coal seams at Avoca, five miles east of Williston, was more sandy. It was a strong, compact structureless clay, composed mostly of a very fine sand with a little clay substance. It was free from concretions and iron was not abundant, but it contained a large percentage of lime. It required a little longer time to slake than many, four and a half hours for the test piece, but could be prepared readily. It took 28.1 per cent. of water to bring it up to its best plasticity, which was good. It had an air shrinkage of 7.1 per cent. and cracked somewhat on drying, the tensile strength being 67 pounds. The burning tests were as follows:

	Cone 010	Cone 05	Cone 03
Fire shrinkage	0.3 per cent	1.8 per cent	failed by swelling and became porous
Color	light red	red to browh	dark brown
Absorption	20.4 per cent	14.8 per cent	

It was incipiently fused at cone 04, vitrified at cone 01 and viscous at cone 1. The bricks which were not cracked were weak. This clay is probably valueless.

No chemical analyses were made of these clays, but an analysis of a clay from this locality shows the following composition[1].

	Per cent.
Silica	57.80
Alumina	9.47
Ferric oxide	3.16
Lime	7.91
Magnesia	2.84

At White Earth the river has cut a valley about 150 feet deep. Along the sides are good exposures of the Laramie. About three miles south of the town, in the east bluff, is exposed a good seam of coal averaging about six and one-half feet in thickness. Over the coal is four feet of compact clay, which has but little grittiness. It is, however, highly calcareous, containing many fossil shells. Over-

[1] E. J. Babcock: N. Dak. Geol. Survey, Vol. I, p. 40.

lying this clay is 20 inches of lignite and then another clay bed, about four feet of which is quite clayey and then rapidly grades into sand.

This clay (No. 5102) is compact, structureless, fine-grained and contains a little very fine sand. It is seemingly quite free from any iron concretions and from lime. It slakes easily and took 29.9 per cent. of tempering water. Its plasticity was good, the air shrinkage was 5.4 per cent. and the clay dried without cracking.

The results of burning were as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	1.0 per ct.	6.8 per ct.	8.0 per ct.	10.5 per ct.
Color	red	red	red to brown	dark brown
Absorption	19.8 per ct.	11.1 per ct.	3.6 per ct.	0.25 per ct.

The bricklet burned to cone 05 was steel hard, and they were all strong, while those burned to cones 03 and 01 were very strong and dense. The bricklet burned to cone 01 was cracked, but the others were not. Incipient fusion occurred at cone 06, and vitrification at cone 1, and the clay did not become viscous before cone 11.

This clay would make an excellent stiff-mud common brick, especially if grogged a little to keep up the fire shrinkage, and probably a paving brick could also be made from it . It is also possible that vitrified ware such as drain tile and hollow block could be manufactured from this clay, especially if mixed with a little anti-shrinkage material.

About 50 feet above this clay occurs a white weathering, fine, clayey sand, which has washed down into the valley and has probably given the town its name of White Earth. The reason it weathers white is due probably to the soluble alkaline and calcareous salts present. This material is useless as a clay.

Along the valley of the Mouse and Des Lacs rivers, from Velva to beyond Kenmare, are many exposures of lignite with the associated sands and clays. Many coal mines have been opened and a few brick companies have started. As yet only two which make use of the Laramie clay have produced any brick. The coal mines and the brick industry are best developed around Kenmare.

The plant of the Kenmare Hard Coal and Brick Company is located two and a half miles south of the town on the west side of the valley. The coal mined is about four feet thick. Although five to six feet of sandy clay underlie the coal, only that over the coal is dug to any extent. A pit about 40 feet deep has been opened.

The material is by no means uniform in character. Some of the layers are more sandy than others, and the percentage of lime is variable. A sample (No. 5304) taken about five feet above the coal represents quite well the average clay.

This is compact and structureless, rather hard, but crushed easily in the rolls and pulverizer used. It contains a good deal of fine sand, and is carbonaceous, ferruginous, and highly calcareous. It slaked easily and was brought to a good plasticity with 20.6 per cent. of tempering water. The air shrinkage was 4.9 per cent., but the bricklets checked a very little. Trouble is also experienced at the plant, which employes a steam drier, with checking when the brick are dried in 25 hours. The tensile strength was 118 pounds.

The results of the burning were as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.8 per ct.	0.9 per ct.	0.6 per ct.	0.3 per ct.
Color	light pink	light pink	light pink	buff to green
Absorption	22.6 per ct.	23.1 per ct.	23.1 per ct.	22.0 per ct.

The bricklets cracked somewhat in burning, due to the expansion of the lime, but were fairly strong. The stiff-mud brick manufactured from a mixture of the whole bank of clay burn reddish, often with greenish surfaces, which are usually checked to a slight extent. The dry press brick do not check and burn to a fairly uniform red color. The clay tested was incipiently fused at cone 2, was vitrified at cone 4, and was viscous at cone 6.

A sample (No. 5303) of the clay overlying the coal was taken some 1,000 feet or so in the mine. This is like the clay collected from the pit in its physical appearance, and is also highly calcareous, but may be a trifle less sandy. It required 24.6 per cent. of tempering water. The plasticity was good, and the air shrinkage was only 4.4 per cent. The tensile strength was 99 pounds. The bricklets cracked very little in drying. The behavior in burning is shown in the following table:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.5 per ct.	0.8 per ct.	1.0 per ct.	0.9 per ct.
Color	light red	buff	buff	buff and green
Adsorption	21.2 per ct.	21.8 per ct.	16.8 per ct.	19.8 per ct.

The bricklets burned to cone 03 and above were cracked badly, while those that burned to cone 05 seemed quite strong. Incipient fusion occurred at cone 2, vitrification at cone 4, and viscosity at

cone 6. This clay is not suitable for the manufacture of any stiff-mud wares other than common brick because of the tendency to check.

Over the coal seam of the Diamond mine, located a mile south of Kenmare, in the east bluff, is five to six feet of a very sandy, calcareous clay similar to that used at the brick plant. In this clay in places there are lenses four to six inches thick and five to ten feet long, of a smoother and more plastic clay.

At the Smith-Kenmare mine, two and a half miles north of Kenmare on the east shore of Lake Des Lacs, the coal seam is about six feet thick, and this is overlain and underlain by clay. The overlying clay (No. 5301) is strong and compact, of a rather fine grain, with but little sand which is very fine. The clay is somewhat calcareous. It slaked fairly easily and required about 30.9 per cent. to develop its maximum plasticity, which was good, but sticky. The air shrinkage was 8.4 per cent. and the bricklets cracked but very little on drying. The tensile strength was 153 pounds. The results of the burning tests were:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.1 per ct.	2.3 per ct.	4.0 per ct.	3.8 per ct.
Color	red	red	dark red	dark brown
Absorption	16.3 per ct.	9.7 per ct.	7.8 per ct.	5.3 per ct.

The bricklets were all strong but were checked a little. The one burned to cone 05 was steel hard. Incipient fusion took place at cone 06, vitrification at cone 2, and viscosity at cone 9. Such a clay would make an excellent brick, and possibly a paver. It is doubtful if it could be used for hollow ware because of the tendency to check.

The clay underlying the coal at this mine is similar. It is, however, more sandy. It appears to have little lime but is highly carbonaceous and ferruginous. At the Soo mine, five miles northwest of town, on the west shore of the lake, the coal is worked by an incline. At the entrance of this is a large dump of clay, which evidently comes from beds over the coal. This is much like the clay overlying the lignite at the Smith-Kenmare mine, and has probably about the same properties.

Around Donnybrook are several small coal mines, the seams of which are thin. North of the town two seams are mined. Associated with coal is a very sandy clay and most of the section exposed in the valley is sand. Under the bottom coal seam near the Leigh-Ericson mine, about two and a half miles north of Donnybrook on

the west side of the valley, is a fairly strong shaly clay (No. 5402), which is quite fine-grained but carries a little fine sand. It contains a small amount of lime, but is highly ferruginous and carbonaceous. It required 35.8 per cent. of water to develop its best plasticity, which was good. The air shrinkage was 7.5 per cent., and the tensile strength 99 pounds. The clay dried with but little cracking. The results of burning were:

	Cone 010	Cone 05	Cone 03
Fire shrinkage	0.9 per cent.	3.4 per cent	failed by bloating
Color	light red	brown red	brown, black center
Absorption	14.1 per cent	6.9 per cent	

The clay was incipiently fused at cone 07, was vitrified at cone 03, and became viscous at cone 2. The bricklets were strong, but even the one burned to cone 05 had started to warp in the center. Too much trouble would probably be experienced in burning this clay to make it of much value.

Another brick plant which employs the Laramie clays is established at Burlington. The pit has a face about 35 or 40 feet in height, the top five or six feet of which is glacial till, but this is allowed to fall in and become mixed with the other clays. The clay is, as a rule, very sandy, but there are two or three thin lignitic seams two to three inches thick, near which the clay is smooth and more plastic. The clay is all mixed together, crushed and screened to remove glacial pebbles, limestone and gypsum, and made into brick by the soft-mud process. To every ton or more of clay a barrel full of ashes is added to grog it. A strong red brick of good quality is produced.

The more plastic, fine-grained clay (No. 5602), which contains some grit, was tested. This slaked very easily in ten minutes. It took 24.7 per cent. of tempering water, and the resulting plasticity was only moderate. The air shrinkage was 3.1 per cent., the tensile strength 98 pounds, and the clay dried without cracking. The burning tests were as follows:

	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.7 per cent	1.3 per cent	4.2 per ct.
Color	light red	light red	red and green
Absorption	23.9 per cent	23.8 per cent	16.8 per cent

The bricklets were strong and burned without cracking. The clay was incipiently fused at cone 2, vitrified at cone 4, and viscous

at cone 6. This makes a good material for common brick, and could also probably be manufactured by the stiff-mud process. This clay could not be vitrified, as the danger of overburning would be too great, and it would also crack when brought to the temperature of vitrification.

The above descriptions show the character of the clays associated with the lignite in the northern part of the state. Those in the southern and central part, along the Northern Pacific railroad and north and south of it, are quite similar in character. In the following discussion the clays along the railroad will be first treated, in the order of their occurrence from east to west, then those north of the railroad, and finally those south of the track.

At Wilton the Washburn Lignite Coal Company has established a brick plant, which is operated in connection with their mine. Both stiff-mud and dry-press brick are made. The clay which is used underlies the coal. The coal seam is about five feet thick and is reached by a shaft 56 feet deep. The clay is obtained from two pits, one about 1,500 feet north of the shaft, the other about the same distance south. In the north pit about 10 feet of clay was exposed; the upper eight feet is a fairly smooth plastic clay, then six inches of a very sandy clay underlain by three and one-half feet of blue clay, which is more sandy than the upper member. The clay is somewhat shaly and is slightly hardened, but is easily crushed and tempered, slaking very quickly. The sample (No. 6501) was taken across the entire exposed face. It required 24.6 per cent. of water to bring it up to its maximum plasticity, which was very good. The tensile strength was 278 pounds, and the air shrinkage 7.5 per cent., but the clay dried without checking, except a little on the surface. The burning tests were as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.3 per ct.	0.8 per ct.	1.0 per ct.	failed by warping
Color	orange	light red	light red	greenish
Absorption	15.8 per ct.	13.5 per ct.	13.1 per ct.	3.9 per ct.

The bricklets burned to cone 05 and 03 were strong and were not checked or warped. The clay was incipiently fused at cone 02, was vitrified at cone 1, and became viscous at cone 3.

In the south pit about eight feet of clay has been opened up. The face shows the following section:

	Feet.
Blue clay, smooth near the roof, grows sandy downwards..........	2½
Sandy clay	2
Very plastic, smooth blue clay...................................	1
Very sandy clay	2½

As a whole the clay (No. 6502) from this pit is more sandy than that from the north one. It is carbonaceous and ferruginous, but lime does not seem to be so abundant. It slaked very easily, and with 21.6 per cent. of water was tempered to its maximum plasticity, which was very good. The air shrinkage was 5.3 per cent., the tensile strength 227 pounds, and the clay dried without cracking.

Its behavior in burning was as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.0 per ct.	0.0 per ct.	0.5 per ct.	2.5 per ct.
Color	orange	light red	light red	greenish
Absorption	17.9 per ct.	16.6 per ct.	15.1 per ct.	5.9 per ct.

The bricklets were strong, and except the one burned to cone 01, which was swelled and warped a little, they were not checked at all. Incipient fusion occurred at cone 01, vitrification at cone 3, and viscosity at cone 4. These two clays work well together and make a good material for wares that do not have to be vitrified, such as building brick, and might also be used for common red earthenware.

Along the Missouri river at Bismarck and to the north are good exposures of the Laramie strata. They are mostly unconsolidated sands with some layers which are cemented by a ferruginous or calcareous cement. About 50 feet above the river, just north of the railroad bridge and near the eastern end of it, about six feet of a shaly, laminated clay outcrops. The upper part is more sandy, gray in color and grades into a fine-grained plastic clay, with but little grittiness below, and of a yellow and chocolate color. As the clay occurs in the bluff it is not homogeneous, the different layers varying greatly, so that the clay would have to be mixed thoroughly if it were to be used.

It (No. 6402) slaked very easily and required 33.3 per cent. tempering water to develop its best plasticity, which was but moderate. The tensile strength was, however, high, being 247 pounds, and the air shrinkage was 7.2 per cent. The clay dried without any checking whatever. The results of the burning were as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.0 per ct.	0.4 per ct.	0.5 per ct.	5.0 per ct.
Color	light red	light red	red	red to brown
Absorption	22.5 per ct.	20.5 per ct.	20.4 per ct.	9.5 per ct.

Incipient fusion took place at cone 01, vitrification at cone 2, and viscosity at cone 4. The bricklets were strong and burned without checking or warping, except the one burned to cone 01, which warped a very little.

An analysis of the lower chocolate colored clay has been made[1].

Silica	58.73
Alumina	14.98
Ferric oxide	5.63
Lime	2.10
Magnesia	0.74
Soda	0.16
Potash	0.988
Water as volatile matter and other matter by subtraction	16.672

This clay would make a good brick and would also be useful for a porous red earthenware, but could not be vitrified or burned very dense.

Across the river similar clays are exposed around Mandan, and are seen along the railroad. At New Salem a brick plant was formerly in operation south of town. A sandy clay (No. 6701) over an important lignite seam, worked by the mining companies here, was utilized. This is a laminated gray, yellow and brown, somewhat shaly clay, like that at Bismarck. It has a few small ferruginous concretions and carbonaceous particles, but is free from the carbonate of lime. It was brought up to its best plasticity, which was good, with 22.9 per cent. of tempering water. The air shrinkage was 7.4 per cent. and the tensile strength 130 pounds. The bricklets and other shapes checked a little. In burning the following determinations were made:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.3 per ct.	0.8 per ct.	1.0 per ct.	failed by swelling
Color	orange red	light red	red and brown	dark brown
Absorption	15.7 per ct.	12.3 per ct.	6.8 per ct.	

The clay was incipiently fused at cone 04, vitrified at cone 01, and viscous at cone 2. The bricklets were strong but were badly checked. If heavily grogged a common red brick could be made from this clay, but it would be weak.

[1] N. Dak. Geol. Survey, Vol. I, p. 40.

At Hebron coal is mined north of the town. From a mine about three miles north coal has been obtained by the Hebron Pressed and Fire Brick Company. The associated clay shale, which burns red, has been mixed with the high grade buff burning Tertiary clays, obtained from a butte a couple of miles north, to make common brick, which were made by the dry-press process, and burned in scove kilns. A smaller proportion of this low grade clay forms a good bond for the much more refractory clay, and is still employed for this purpose.

The company intends to develop the coal mine, a mile or so northwest of their clay pits, on section 3, T. 140, R. 90.

The following section is shown here:

	Feet.	Inches.
Sandy, ferruginous and carbonaceous clay	9	
Lignite	7	
Plastic, highly carbonaceous clay		5 to 12
Lignite	1	
Plastic, carbonaceous clay	2	

All these clays contain more or less sulphur which would give too much trouble in burning to make them of value. The bricklet burned to cone 05 bloated very badly, the interior forming a porous black mass.

Richardton is situated on a high divide several hundred feet above the valleys to the north and south. Most of the layers exposed in the badlands north of the town are sandy. A very sandy clay which is ferruginous and carbonaceous was dug for the manufacture of brick at Richardton. It was obtained in the valley about a mile north of town, and nearly 200 feet lower than the plant. During the past season it has been dug near the plant, the material from the excavation for the Catholic college being used. Six inches of loam and about three feet of the underlying yellow, sandy clay was taken out. The clay (No. 3202) is mostly a fine sand, with considerable fairly coarse sand, and some clay substance. Lime particles, as well as carbonaceous and ferruginous ones, are present. The clay is prepared in soak pits. With 25.9 per cent of tempering water it is worked up into a good plastic mass. The air shrinkage was 7.1 per cent, the tensile strength 339 pounds, and the clay dried without checking. Its behavior in burning is shown in the following table:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.3 per ct.	0.3 per ct.	0.5 per ct.	3.0 per ct
Color	light red	light red	red	dark brown
Absorption	19.6 per ct.	19.6 per ct.	17.6 per ct.	12.0 per ct.

The bricklets were strong, and with the exception of the one burned to cone 01, did not check at all. The clay was incipiently fused at cone 1, vitrified at cone 3 and viscous at cone 5. A strong red brick can be made from this clay, but it is of little value for anything else.

Just northeast of Richardton is a coal mine where the lignite is overlain by two feet of a compact shaly clay (No. 3201). It is very fine-grained, and contains no grit which can be detected between the teeth. It is, however, calcareous. It slaked easily and took 29.0 per cent of tempering water to develop its maximum plasticity, which was good. The clay checked somewhat on drying, although the shrinkage was only 4.0 per cent. The tensile strength of the air dried clay was 133 pounds.

The results of the burning tests were as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.9 per ct.	5.4 per ct.	7.3 per ct.	9.8 per ct.
Color	light red	light red	red	red brown
Absorption	23.1 per ct.	10.9 per ct.	11.1 per ct.	1.5 per ct.

The clay was incipiently fused at cone 06, vitrified at cone 1, and viscous at cone 7. The burned clay was strong and checked but very little; that burned to the higher temperature was, however, warped somewhat.

A chemical analysis of this clay shows the following composition:

	Per Cent.
Silica	61.67
Alumina	17.41
Ferric oxide	3.65
Lime	2.32
Magnesia	3.71
Loss on ignition	6.07
	94.83

The shrinkage in the clay is too great for it to be used alone. It may be that it could be grogged so that brick, and possibly paving brick, tile and other vitrified wares could be manufactured from it.

Coal also outcrops at Dickinson near the level of or not far above the Heart river. Typical Laramie clays are associated with the

lignite. These are used by the Dickinson Pressed Brick and Fire Clay Company to mix with their higher grade, refractory clays to get a better bond. The clay is obtained from pits on the north bank of the river, just back of the brick plant. It is shaly and varies from a gray or blue, fine-grained, smooth, plastic clay, to a sandy, ferruginous one.

Just east of Dickinson, at Lenneiville's place, coal has been mined for local use. There is exposed here:

	Feet.	Inches.
Weak, shaly, clayey sand, passing into sandy blue clay, highly calcareous	10	
Lignite		2
Weak, shaly, very sandy clay, highly calcareous	3	
Lignite		4
Strong, compact, shaly clay	3½	
Lignite	10	

The two upper layers of clay were too sandy to become plastic but the 3½-foot layer (No. 4903), directly over the thicker seam of lignite, develops a good plasticity with 32.2 per cent of tempering water. It is a fairly fine clay with only a little grittiness. It is very carbonaceous and also contains iron and lime. It had an air shrinkage of 6.3 per cent and a tensile strength of 187 pounds. The bricklets did not check on air drying, except a very little. On burning the clay gave the following results:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.5 per ct.	4.0 per ct.	6.0 per ct.	9.9 per ct.
Color	chocolate	brown red	dark brown red	dark brown
Absorption	17.6 per ct.	14.8 per ct.	9.5 per ct.	2.19 per ct.

The bricklets were strong, became steel hard at cone 05, and did not warp or crack. The clay was incipiently fused at cone 04, vitrified at cone 1, and viscous at cone 8. The shrinkage of this clay is probably too great to be used alone, and it would have to be grogged. Strong red brick could be made from the grogged clay, and possibly other low grade wares such as drain tile.

North of the Northern Pacific track coal outcrops in all deep valleys such as those of the Missouri, Little Missouri and Knife rivers, and their tributaries, Spring and Crooked creeks being the principal ones. Associated with the seams is more or less clay. The seams throughout the basin of the Knife river and Spring creek are thin, and the clays associated with them are very impure and sandy. The greater portion of the Laramie exposed in this region is ferruginous and calcareous sand.

On the Knife river at Broncho and for several miles east, little but ferruginous and calcareous sand is exposed. The lignite seams are less than a foot thick and impure. A sample of a white, seemingly plastic clay, which is two feet thick, appears in the cut bank about three miles below the post office of Broncho, and about eighty feet above the river is a fine clay, with little or no grittiness, but it is so calcareous as to be worthless as a clay. The following section occurs at Broncho:

	Feet.	Inches.
Alternating layers of ferruginous and gray sand with thin layers of impure limonite, gray layers predominate..	130	
Sandy, plastic clay		6
Ferruginous sand	22	
Shaly clay and sand; clay is clean and highly calcareous and contains calcareous concretions	7	
Ferruginous, sandy, compact clay, which is lean and calcareous	7	
Gray sand	7	
Ferruginous sand or unexposed to river	20	

On Spring creek, north of Broncho, no clay or lignite is exposed, there being only gray and brown sands, with occasionally a little impure, sandy clay, and thin, poor lignite seams. Several miles up the Knife river, at Rockspring, the section exposed in the cut bank opposite the mouth of Crooked creek shows nothing but ferruginous sand, very thin, impure lignite, and sandy clay. A cut bank a few miles from the mouth on Crooked creek shows the following section:

	Feet.
Ferruginous sand	20
Fine, clayey sand	6
Hard, ferruginous sandstone, concretionary	4
Hard clayey sand and sandy shale, some layers more sandy, others more clayey. Contains many small ferruginous and calcareous concretions. Not plastic	15
Lignite	1
Impure hard sand, with clayey layers	15
Lignite	2½
Ferruginous sand, some thin, carbonaceous layers	20

Near the headwaters of the Knife river and tributaries the coal becomes more plentiful, as it is along the Little Missouri river. The clay associated with it is as a rule impure and sandy. The tops of the divides and buttes are about 200 feet or more above the creek bottoms. The refractory, light burning clays are exposed

in the upper part, and near the bottom the Laramie sand with a few seams of lignite appears, the thickest seam noted being about six feet thick.

Along the Little Missouri river many coal outcrops occur,[1] some of which are thick and extensive. Associated with these seams are typical Laramie clays. At Manning's old ranch on the Little Missouri, five miles below the mouth of Jim creek, beds 500 feet thick are exposed. The upper part contains the high grade Tertiary clays, which are separated from the coal-bearing horizon by 100 feet or more of sand. In the upper part of the coal measures for 250 feet the material is mostly a ferruginous sand with some quite pure layers, while others are very carbonaceous. Scoria is abundant, however, showing that coal at least in thin seams has been present. The lower 150 feet shows at least two thick seams of lignite, one four feet and the other one six feet. Over the top seam is four feet of clay. It is very sandy and lean, and is highly calcareous. Ten feet of a compact, shaly clay (No. 3911) overlies the bottom seam. It is uniformly fine-grained with but little grittiness. It is very carbonaceous, containing thin lignite layers, but has but little lime.

It slaked fairly easily and took 35.5 per cent of tempering water. The plasticity was good, but very sticky. The air shrinkage was high, 9.0 per cent, and the clay cracked on drying. For this reason the briquette had a low tensile strength, an average of only 58 pounds. Its behavior in burning was as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.5 per ct.	4.2 per ct.	5.5 per ct.	bloated and cracked
Color	chocolate red	dark red	dark red	dark brown
Absorption	15.7 per ct.	5.7 per ct.	4.1 per ct.	

The bricklets were strong, but those burned to cone 05 or above were cracked and warped a little. Incipient fusion occurred at cone 06, vitrification at cone 01, and viscosity at cone 7.

An analysis of this clay shows:

Silica	56.42
Alumina	16.93
Ferric oxide	7.47
Lime	2.61
Magnesia	3.16
Loss on ignition	7.58
	94.17

[1] L. H. Wood, N. Dak. Geol. Survey, Vol. III, p. 41.

Both the air and fire shrinkage of this clay is too great for it to be used alone. Most of the sand in the neighborhood is too calcareous to be valuable for mixing with it. If ever the overlying clays are used, this clay may be employed to mix with them to furnish a bond at low temperatures, or to give a mottled brick with a lighter body.

South of the Northern Pacific railroad coal outcrops more abundantly than it does to the north, along the numerous rivers and creeks tributary to the Heart and Cannon Ball rivers. The associated clays are more abundant and less sandy.

South of Glen Ullin, along the Heart river and Heart Butte creek are many exposures. At a local mine, about three miles northwest of Heart Butte, five or six feet of sand and three feet of clay overlies the coal, the upper foot being highly ferruginous, carbonaceous and sandy, and the lower part somewhat poorer. The lower two feet (No. 1802) is a weak, shaly clay, with shell and leaf fossils. It has a medium grained clay body with a good deal of fine sand. Some of the layers are especially sandy and calcareous. It is bluish gray in color with yellow and brown streaks, which are more ferruginous. It slaked easily and with 31.6 per cent of tempering water developed a good plasticity. The air shrinkage was 6.9 per cent, and the tensile strength 116 pounds. The clay checked somewhat on drying. On burning it bloated badly and formed a black, porous, slaggy interior, probably due to the large amount of sulphur present. Such a clay is valueless.

A little further south, where the mail road from Glen Ullin to Leipzig crosses the Heart river, the cut bank exposes the following section, which shows the character of the beds here:

	Feet.	Inches.
Sand capped by a layer of sandstone	15	
Shell marl, with a ferruginous cement		22
Gray, sandy clay		6
Gray sand		4
Compact, light bluish gray, plastic clay	3	6
Lignite		26
Brown ferruginous sand		14
Lignite	3	
Yellow sand, more or less streaked and laminated, cross bedded and concretionary	100	

The three and a half foot layer of clay (No. 1705) is of a fine uniform texture, with scarcely any grit between the teeth. It is quite free from concretions. It is gray in color, but is stained yellowish and

brownish by iron and carbon. It slaked readily and took 30.8 per cent of tempering water for its maximum plasticity, which was good. The air shrinkage was 6.9 per cent, the tensile strength 116 pounds, and the clay dried without checking at all. Its behavior is shown in the following table:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	4.7 per ct.	6.0 per ct.	9.9 per ct.	cracked and badly warped
Color	light red	red	red to brown	
Absorption	11.1 per ct.	7.2 per ct.	0.5 per ct.	

The clay was incipiently fused at cone 07, vitrified at cone 03, and became viscous at cone 3. The bricklets were strong, but they were checked a little. The fire shrinkage of this clay is too great to permit its being used alone.

A clay (No. 1701) from the same horizon about a mile south of the river showed similar properties, but contains a few small ferruginous segregations which probably contain a little sulphur, since when the clay is burned above cone 03 it is bloated a little and shows a black, porous core. It took 27.02 per cent of tempering water, developing a good plasticity, The air shrinkage was 6.3 per cent and the tensile strength 200 pounds. The results of the burning tests were:

	Cone 010	Cone 03	Cone 01	Cone 2
Fire shrinkage	3.0 per ct.	3.7 per ct.	7.5 per ct.	failed by warping
Color	light red	red	dark brown	green brown
Absorption	11.5 per ct.	8.4 per ct.	0.6 per ct.	

Incipient fusion took place at cone 06, vitrification at cone 03, and viscosity at cone 4. The bricklets burned to cone 03 and above were warped, the others were strong and all right. This clay can be grogged and used at low temperatures for red brick, and possibly common low grade red earthenware.

Further south around Leipzig and Antelope creek are many outcrops of coal about on the level of the creek. In general the overlying clay is very impure and sandy.

Following up the Heart river valley from the bridge south of Glen Ullin, the bluffs are composed almost entirely of sand. About 75 feet above the water level there is a coal and clay horizon about fifteen feet in thickness. The clay is light gray and sandy. South of Richardton, the following section is exposed:

	Feet.	Inches.
Sand and sandstone, nearly all ferruginous, also concretionary	80	
Lignite, contains a couple of sandy partings	3	6
Impure ferruginous sandy clay	1	
Fine gray sand	5	
Carbonaceous, ferruginous, shaly clay, somewhat sandy		14
Fine, gray sand	10	
Lignite	1	
Impure carbonaceous clay	4	
Fine, gray sand, more or less carbonaceous, ferruginous and clayey	25	
Lignite		6
Sand, with small lenses of lignite	30	

Associated with the thin lignite seams is more or less clay a few inches thick, but it is all sandy and ferruginous.

As along the Heart river, so along the Cannon Ball, coal and its associated clays are found. At Mott, a cut bank of the river shows mostly sand, but there are a couple of thin lignite seams, about two or three inches thick, separated by four feet of clay and ten feet of sand. Clay No. 1501 is compact, and has a fairly fine, uniform body, but contains carbonaceous and ferruginous particles which are sandy. The clay is of a light bluish-gray color, stained buff on the surfaces with ferric oxide.

With 26.5 per cent of water the clay can be tempered to a good plasticity. The air shrinkage was 5.1 per cent and the tensile strength 110 pounds. The clay checked a little on drying. The burning tests gave the results following:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.9 per ct.	0.9 per ct.	6.7 per ct.	warped and swelled very badly
Color	light red	light red	red	dark green enamel
Absorption	18.8 per ct.	18.9 per ct.	5.4 per ct.	

The bricklets, except the one burned to cone 1 were strong and were not injured by checking or bloating during the burning. The clay was fused incipiently at cone 02; it was vitrified at cone 1 and became viscous at cone 2.

An analysis of this clay shows it to have the following composition:

	Per Cent.
Silica	57.94
Alumina	17.46
Ferric oxide	4.58
Lime	4.14

Magnesia	3.84
Loss on ignition	7.69
	95.65

This clay would not, if used alone, be satisfactory for vitrified brick. It might, however, be used for such a purpose if carefully mixed with other clay of the right character. It could be used for red building brick and as a grog to produce with a lighter body a mottled pressed brick.

Along the North Fork of the Cannon Ball river most of the banks are sandy. Some twenty-five miles above Mott, at Clark's ranch, seven feet of coal outcrop and is overlain by three feet of clay which is of a fine texture, but lean.

At New England no clay or coal outcrops in the banks of the river nor for a couple of miles west, but about a mile north of the post office, in a pit on the side of a small hill, is exposed some four or five feet of sand overlying a yellow, sandy clay. The texture of the clay (No. 501) is quite fine and uniform. It contains considerable iron and carbonaceous material, but seems quite free from lime. It slaked easily, and with 25.0 per cent of water was moderately plastic. The air shrinkage was 2.9 per cent and the tensile strength 167 pounds. The clay dried without cracking. The results of the burning tests are shown in the following table:

	Cone 05	Cone 03	Cone 1
Fire shrinkage	3.6 per cent	7.8 per cent	8. 3 per cent
Color	light red	greenish brown	brownish green
Absorption	18.2 per cent	1.3 per cent	3.5 per cent

The bricklets were strong, but cracked a little in burning. The clay was incipiently fused at cone 04, vitrified at cone 1, and viscous at cone 6. This clay would make an excellent common brick, preferably by the wet mud process, but the fire shrinkage is probably too high for it to be burned dense enough for a paving brick.

A little further north, two miles from the river, is a small coal mine, the lignite being mined for local use. Overlying the six-foot seam is about two feet of bluish-gray clay (No. 602), the rest of the overburden being sand. The clay is of a medium fine texture with some sandy patches. Gypsum occurs in the clay, as well as carbonate of lime. It slaked easily and required 35.5 per cent of water to temper it to its maximum plasticity, which was good. The air shrinkage was 9.3 per cent, the tensile strength 124 pounds, and the clay checked badly on drying. Although it did not become

vitrified until cone 5, it cracked very badly when burned even to cone 010. This is probably due to the large amount of limestone and gypsum. This clay is of no value.

About fifteen miles east of New England, just north of Black Butte on section 35, T. 136, R. 95, is a small coal mine. The five or six feet of coal is overlain by two feet of clay (No. 2201), and that in turn by ten feet of sand. The clay is strong and compact, of a bluish-gray color, with laminations of lighter and darker colored material. It is fine-grained and with very little grittiness. It contains a little mica, is somewhat ferruginous, but low in lime. An analysis shows the following composition:

	Per cent.
Silica	57.12
Alumina	19.24
Iron	4.98
Lime	2.26
Magnesia	3.00
Loss on ignition	8.19
	94.19

The clay required 38.0 per cent of tempering water and the resulting plasticity was good. The air shrinkage was 7.9 per cent and the tensile strength 111 pounds. The clay dried practically without checking. Its behavior in burning is shown in the following table:

	Cone 010	Cone 05	Cone 01	Cone 2
Fire shrinkage	0.8 per ct.	4.0 per ct.	9.4 per ct.	failed by swelling a little
Color	red buff	red	red brown	dark brown
Absorption	16.3 per ct.	13.5 per ct.	.27 per ct.	

Incipient fusion took place at cone 05, vitrification at cone 01, and viscosity at cone 8. The bricklets were strong, and not checked or warped at low temperatures but at cone 01 and above the shrinkage is too great, and the clay warped. This clay could be grogged and brick and earthenware manufactured which could probably be burned quite dense.

Similar layers of clay occur with the coal seams in the neighborhood, some of the wells exposing it only a few feet from the surface.

West from New England the general elevation of the country rises, and the coal-bearing beds are not again exposed until the divide has been crossed and the creeks emptying into the Little

Lignite bed 33 feet thick, and overlying clay, at the Russell ranch on Sand creek, Billings county. Lower portion of coal bed covered by talus.

Missouri reached. In the cut banks of these streams much lignite is found, some seams being very thick, and considerable clay is associated with the coal.

At Russell's ranch on Sand creek, five miles down stream from the post office of that name, the thickest coal seam in the state. thirty-three feet, outcrops in the cut bank of the creek. The following section is exposed:

	Feet.	Inches.
Sand, and some gravel, consolidated to a soft sandstone....	35	
Blue clay (No. 201)	2	6
Impure, clayey limonite		6
Blue clay, contains more or less iron in concretions........	9	6
A lighter bluish gray clay, somewhat carbonaceous (No. 205)	4	
Dark blue carbonaceous clay	1	
Lignite	3	6
Light bluish gray clay (No. 208)........................	3	6
Lignite	33	

Three samples of the clay from this section were tested, one from the upper two and one-half foot seam of blue clay (No. 201), another from the four foot seam of lighter clay (No. 205), and another from the seam between the coal (No. 208). Sample No. 201 is fine uniform clay, the grittiness being but slight. It is soft and structureless and is easily slaked. It took 23.4 per cent of water to temper it to its best plasticity, which was very good. It shrank 2.5 per cent in drying and had a tensile strength of 203 pounds. It showed a slight tendency to check on drying. The results of the burning tests were as follows:

	Cone 05	Cone 03	Cone 01	Cone 3
Fire shrinkage	2.0 per ct.	1.2 per ct.	2.0 per ct.	14.1 per ct.
Color	light buff	light buff	buff to green	light green
Absorption	26.4 per ct.	25.2 per ct.	23.4 per ct.	

The bricklets did not shrink much at first when burned at comparatively low temperatures but checked considerably, probably due to the lime present. The clay was incipiently fused at cone 2, vitrified at cone 4 and became viscous at cone 6. It would not be good for much except common brick and is not particularly good for that.

Clay No. 205 is of a fine uniform grain, similar to the above. It slaked very easily and was very plastic with 22.3 per cent of water. The air shrinkage was 3.6 per cent and the tensile strength 221 pounds. The clay dried without checking. An efflorescence of salt was formed on the dried clay. Its behavior in burning was as follows:

	Cone 010	Cone 05	Cone 03
Fire shrinkage	2.1 per cent	4.3 per cent	failed by warping
Color	light buff	buff	olive green
Absorption	17.3 per cent	11.6 per cent	

The bricklets burned to cone 010 and 05 were quite strong and not cracked. The clay could not be burned dense as it became viscous too rapidly. Incipient fusion occurs at cone 01, vitrification at cone 2 and viscosity at cone 3. This clay is not suited for any purpose except a common brick, and is not well adapted for that.

The clay (No. 208) from between the coal seams is very fine and smooth, with a little carbonaceous material scattered through it, and somewhat stained with iron. It did not slake so readily as did the coarse overlying clays. It also required more tempering water, 34.2 per cent, but the plasticity was very good. The air shrinkage was 5.0 per cent and the tensile strength 112 pounds. The clay checked a very little on drying. It burned as follows:

	Cone 010	Cone 05	Cone 03	Cone 3
Fire shrinkage	3.6 per ct.	9.0 per ct.	10.1 per ct.	12.0 per ct.
Color	red	red	red brown	dark brown
Absorption	14.2 per ct.	5.7 per ct.	4.2 per ct.	0.47 per ct.

The clay was incipiently fused at cone 05, vitrified at cone 3, and was not viscous until cone 8. The bricklets were strong. Those burned to cone 03 or higher were warped, due to the high shrinkage. This clay would have to be grogged to be used, and then could be employed for brick and red earthenware, and could possibly be vitrified.

The Laramie clays are thus seen to have a wide extent. They are, however, not of great economic importance. The great majority of them are sandy and of no value. Those which are plastic enough to be used usually have a high air shrinkage, and even in the manufacture of common stiff-mud brick trouble is experienced by checking. Some have a low shrinkage and are plastic enough to be worked by the stiff-mud process for the manufacture of brick and common red unglazed earthenware. In the majority of the clays, which are all of low fusibility, and especially in the sandy, calcareous ones, the points of incipient fusion and viscosity are too near together to allow any ware made from them to be vitrified. Those clays in which these points are separated are all of very high fire shrinkage. Possibly by properly mixing these latter clays with more sandy ones, or with some other kind of grog, a material

could be composed which would have sufficient [illegible] molded, and low enough shrinkage so that it [illegible] checking, and burned dense without failure [illegible] periments with vitrified wares carried on with these [illegible] so far either failures or only partial successes.

CHAPTER VIII.

TERTIARY CLAYS.

The beds of clay and sand overlying the Laramie have already been briefly discussed. Over an area lying between the meridians passing through Hebron and Belfield and the 8th and 12th standard parallels, roughly fifty miles east and west by ninety miles north and south, these strata outcrop in nearly all the high elevations or those over 2,450 feet above sea level. This elevation is reached only in the buttes and divides. All the higher buttes are capped by sandstone which reaches a maximum thickness of about 400 feet in the Killdeer Mountains. This sandstone is cemented by calcareous or ferruginous material. It is for the most part soft and unconsolidated and is only protected from rapid erosion by the overlying layers of firm sandstone. Practically no clays are found in this horizon and they are confined to the one below.

This white clay horizon is from 50 to 150 feet thick and lies between 2,450 and 2,600 feet above sea level. The probable distribution of these clays is roughly shown on the accompanying map. They are not so abundant south of the railroad as they are to the north, the general elevation of the country being lower. In the vicinity of the Killdeer Mountains they underlie a very large territory, but are not so thick or so pure as they are further south. They reach their maximum thickness in the neighborhood of Dickinson and Gladstone, though north of Hebron they become quite thick. In both these localities we find very pure plastic clays from 10 to 20 feet in thickness overlying sandy clays, high in silica, which are fairly plastic and are good fire clays, and attain a thickness of from 30 to 50 feet.

These clays, especially the white sandy fire clays found below the plastic clays are, as a rule, remarkably uniform, considering the large area over which they were deposited. The other clays vary considerably in their physical properties, but are very generally low in lime, and other fluxing constituents and are of a refractory nature, except those in the southwestern part of the area. They usually burn white, gray, or buff, though some are high in iron and burn to a brown color. They are compact, massive, and usually

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a brown color. They are compact, massive, and ...ally

structureless, are at times laminated, but rarely shaly. Induration has not taken place to any extent so that the clays are soft and easily mined and prepared. In texture they vary from extremely fine-grained to sandy clays with but little clay substance. They slake easily, especially the sandy ones. The great majority develop a plasticity which is sometimes exceptionally good. Even the sandy clays become moderately plastic although some are lean. The amount of tempering water required ranges from 61.8 per cent for a highly calcareous and worthless clay occurring at Sandcreek to 15.3 per cent for a very sandy lean clay outcropping at Hebron. The greater portion of these clays took between 22 and 28 per cent, the average being 26.3 per cent.

The air shrinkage is generally low and most of the clays dry without cracking. The calcareous clay from Sandcreek had the maximum shrinkage, 19.0 per cent and the minimum shrinkage was 1.0 per cent. The average air shrinkage of the clays tested was 5.4 per cent.

Although they have such a good plasticity, being extremely good modelling clays, the tensile strength of the air dried clay is not very high. The highest strength recorded was 300 pounds and the lowest 40 pounds. Many of the clays, particularly the calcareous ones with high shrinkages, crack so on drying that it was impossible to determine their strength. The strength of the sandy clays is generally low. Even some of those whose plasticity is very good had a tensile strength of less than 100 pounds. The average strength of the clays tested was 110 pounds.

The clays are generally refractory although it is doubtful if any are "number one" fire clays, on account of the large amount of silica. The white sandy clays are very good fire clays and many of them are unaffected at 3000 degrees F. The majority of the plastic clays tend to fuse at temperatures below this point. These clays are remarkable for the wide range between the points of incipient fusion and viscosity. A selected sample from the deposit north of the railroad track, between Gladstone and Dickinson, had a range of 25 cone numbers or 900 degrees F. A great many of them have a difference in these points of from 600 degrees to 800 degrees F. The fire shrinkage is apt to be rather high. As already noted most of the clays burn to light colors, although some which are high in iron give mottled buff and dark brown bricks.

In describing these clays those at present available, near the Northern Pacific railroad will be first discussed, followed by an account of those to the north and south of the track.

Clays Near the Northern Pacific Railroad.—The most eastern locality for these high grade clays is in the buttes north of Hebron. Further in this direction the general elevation of the country has been so reduced by erosion that even if they had ever existed there, they have been long since removed. Hebron itself has an elevation of 2,160 feet above sea level. About 300 feet above the town, on section 11, T. 14, R. 90, is a fine exposure of these clays, which are here mined by the Hebron Pressed and Fire Brick Company.

The following section is shown:

	Feet.	Inches.
Sand with carbonaceous clayey layers....................	10	
Impure limonite		2
Impure, dark gray or blue, carbonaceous and ferruginous, shaly clay (No. 2901)	4	
Impure, ferruginous, sandy clay (Nos. 2902-3)............	10	
Gray to almost black, carbonaceous clay, more or less spotted	5	6
A light gray, sandy clay, stained but little with iron, most plastic near the top, grows more lean and sandy downwards (Nos. 2904-8)	50	

Below this, exposed in a well, there is said to be twenty feet of the sandy clay similar to that above.

In the bottom part of the fifty feet of sandy clay there is a lens of impurer clay (No. 2909) similar in texture to the surrounding clay, but richer in carbon and iron. This lens is thirty feet long by five feet high in the center. A lens of lignite which reached a thickness of four feet was found at the west end of the pits.

A sample from the upper four-foot, impure clay seam (No. 2901) had a fairly fine-grained clay body with a good deal of grit. It showed many carbonaceous (fossiliferous) and ferruginous layers and partings. It was bluish gray in color, with many of the surfaces brown or red. It slaked fairly easily and required 27.1 per cent of water to temper it to its best plasticity, which was good, but sticky. The air shrinkage was 5.6 per cent and the tensile strength 175 pounds. The clay showed a tendency to check a little on drying. It burned as follows:

	Cone 010	Cone 05	Cone 01
Fire shrinkage	0.3 per cent	3.7 per cent	8.3 per ct.
Color	light red	red	dark brown
Absorption	17.0 per cent	10.5 per cent	0.4 per ct.

Clay bank of Hebron Pressed and Fire Brick Company, showing the white Tertiary clays.

The clay was incipiently fused at cone 03, vitrified at cone 2, and viscous at cone 7. The bricklets were very strong, and the one burned to cone 01 very dense. This latter cracked a little due to excessive fire shrinkage. The clay cannot be heated too quickly, else it will blister. This makes a good material for mixture with the refractory clays below to increase their plasticity, bonding power and density of burning at low temperatures. By proper mixing, this clay could probably be used for paving brick and other vitrified common wares.

Sample No. 2903 was also tested. This is a dark, carbonaceous clay, finer grained and with less sand than the clay above. It required 29.0 per cent of tempering water and became plastic, moulding easily, but it did not adhere well. It had an air shrinkage of 5.4 per cent, but cracked on drying so that its tensile strength was difficult to determine, the best value being 47 pounds.

Its behavior in burning was as follows:

	Cone 05	Cone 03	Cone 01	Cone 5	Cone 10
Fire shrinkage	2.8 per ct.	3.2 per ct.	6.3 per ct.	8.0 per ct.	9.2 per ct.
Color	cream white	cream white	yellow	gray	gray
Absorption				0.8 per ct.	0.7 per ct.

The clay was incipiently fused at cone 1, vitrified at cone 11, and rendered viscous at cone 24. The bricklets were strong, and those burned to cone 01 or less, were not checked by burning. Those burned at higher temperatures were, however, quite badly cracked. The clay is much more refractory than the one above. To be used it would have to be mixed with another clay of less shrinkage.

Two samples from the sandy clay were tested, one near the top (No. 2905), and the other near the bottom (No. 2908), of the fifty feet. The upper sample showed a fine clay body with considerable fine, pure sand. It was more or less spotted with carbonaceous material and stained a little with iron. It slaked very easily and required but 20.6 per cent of water to develop its best plasticity, which was good. The air shrinkage was 3.8 per cent, the tensile strength 122 pounds, and the clay did not check on drying.

The results of the burning test were:

	Cone 05	Cone 03	Cone 01	Cone 5	Cone 10
Fire shrinkage	0.0 per ct.	0.8 per ct.	1.0 per ct.	2.9 per ct.	5.8 per ct.
Color	cream	buff	light buff	light buff	light gray
Absorption	15.9 per ct.			10.6 per ct.	1.8 per ct.

Incipient fusion occurred at cone 8, vitrification at cone 15, but the clay cone did not become viscous at cone 25, although the edges were rounded. The bricklets were strong and did not crack on burning. At cone 15 the clay burned to a dense grayish white body.

An analysis of this sample gave the following results:

	Per Cent.
Silica	73.90
Alumina	16.49
Ferric oxide	1.25
Lime	0.29
Magnesia	0.46
Soda	0.22
Potash	1.20
Water and other volatile matter	5.52
	99.33

The sample from the lower part of the deposit resembled strongly the one taken above. It contained more of the very fine-grained, pure quartz sand and also a little mica. With 18.4 per cent of water it was tempered to its maximum plasticity, which was not quite so good as that of the clay above. The air shrinkage was 3.3 per cent, the tensile strength 157 pounds, and the clay did not check during drying.

Its burning tests were:

	Cone 05	Cone 01	Cone 5	Cone 10
Fire shrinkage	0.3 per ct.	0.5 per ct.	1.8 per ct.	5.2 per ct.
Color	cream	yellow	cream	light gray
Absorption		15.4 per ct.	11.5 per ct.	1.9 per ct.

Incipient fusion took place at cone 9, vitrification at cone 15, and viscosity at some temperature not far above cone 25. The bricklet to cone 10 was warped and swelled a trifle, the others were good and quite strong. The clay is thus very much like the sample from the upper part of the deposit.

This 50-foot bed of clay is used at present for fire and pressed brick. It is fairly refractory, the bricks made from it probably not fusing until a temperature is reached considerably over 3000 degrees F. It is also suitable for stoneware and white earthenware some having been made from it at the plant. For dense and vitrified wares such as stoneware it would have to be mixed with clays of lower fusibility.

The lens of impure clay (No. 2909) is not essentially different in its properties, although it fuses a little easier. It is more sandy than the others and took but 17.6 per cent. of tempering water. The resulting plasticity was but moderate. The air shrinkage was only 2.2 per cent. and the clay dried without checking.

The burning tests were as follows:

	Cone 05	Cone 03	Cone 01	Cone 5	Cone 10
Fire shrinkage	0.0 per ct.	0.4 per ct.	0.7 per ct.	1.4 per ct.	5.8 per ct.
Color	light pink	buff	buff	cream	light gray
Absorption		15.2 per ct.	16.1 per ct.	12.9 per ct.	1.9 per ct.

It was incipiently fused at cone 8, vitrified at cone 13, and rendered viscous at cone 22, fusing to a smooth, gray white, enameled surface. No trouble was experienced in burning the bricklets, and they were strong and very satisfactory. It is not quite so refractory, but otherwise would have the same uses as the surrounding clay.

This clay is traceable a few miles north, east and west, but nowhere else in the neighborhood is it as thick. About three miles north and east of the Hebron Brick Company's deposit there is exposed, in the buttes and breaks at the head of Elm creek, the following section:

	Feet.
Sand	10
Impure, rather sandy clay	8
Light to dark gray, laminated, sandy clay, much like Hebron sandy clay, but darker in color and more sandy	3
Impure, carbonaceous, sandy clay	5
Sand and clay, with a couple of thin, impure lignitic seams	8
White, sandy clay, stained a little yellowish with iron, much like Hebron clay	2½
Unexposed to creek bottom, some impure sand and clay, ferruginous or carbonaceous	100

Two or three miles east of the above section the buttes are mainly sand or impure clay, and coal in very thin seams. Near the tops of the buttes 10 to 15 feet of a cream white, pure, sandy clay outcrop and represent the horizon of the white, sandy, fire clays. Only a couple of miles further east, in the broad valley of Elm creek, the clay seems to disappear. The elevation of the country east of there is probably below that of the clay horizon.

A sample (No. 3104) taken near the above mentioned deposit is a light grayish white clay, spotted with red or brownish iron stains, of a very fine texture and with considerable sand. This slakes very easily. It took 19.7 per cent. of tempering water and its plasticity

was very good. The air shrinkage was 5.9 per cent., the tensile strength 82 pounds, but the clay did not check on drying.

On burning its behavior was as follows:

	Cone 05	Cone 03	Cone 01	Cone 5	Cone 10
Fire shrinkage	1.3 per ct.	1.5 per ct.	2.3 per ct.	6.4 per ct.	4.2 per ct.
Color	buff	light buff	light buff	gray	mottled gray and brown
Absorption		11.6 per ct.	8.9 per ct.	0.5 per ct.	0.5 per ct.

The clay fused incipiently at cone 1, vitrified at cone 8 and was viscous at cone 21. The bricklets were all strong and those burned at cone 01 or under were not cracked. The one burned to cone 5 was cracked a little, and the one to cone 10 was cracked badly.

The mottled color to which this clay burns would, of course, bar it for use as white earthenware, neither is it a fire clay. It would make excellent brick, the mottled appearance of the burned brick being to its advantage. Cheap stoneware and vitrified products also probably could be made from it.

Due north of the Hebron Brick Company's pits the sandy fire clay outcrops for about two miles. It is usually found underlying a thick layer of sand and an impure carbonaceous clay. The fire clay is about 15 to 50 feet thick two miles north of the pits and dies out rapidly to the east and north. A sample of this clay, which is sandy and lean, required but 15.3 per cent. of tempering water. The air shrinkage was 1.3 per cent. and the tensile strength 60 pounds. The clay, of course, dried without cracking. The results of the burning tests were:

	Cone 03	Cone 01	Cone 5	Cone 10
Fire shrinkage	0.7 per ct.	0.3 per ct.	0.0 per ct.	2.0 per ct.
Color	buff	buff	light buff	gray white
Absorption	16.1 per ct.	16.0 per ct.	13.9 per ct.	8.7 per ct.

The clay was incipiently fused at cone 21, the color being pure white, and vitrified at cone 24, viscosity taking place at some temperature higher than 3,000 degrees F.

The bricklets were fairly strong and no trouble was experienced in burning them. This clay is a good fire clay, but is too lean to be used alone except for fire brick and fire clay shapes, manufactured by the soft-mud process.

To the westward the continuation of the clay horizon is seen for several miles, along both sides of Farmer's valley, about 300 feet

above the flat. On the south side of the valley and about three or four miles west and a little north of the town of Hebron this section is shown:

	Feet.
Sand	12
Bluish gray, sandy clay (No. 3001)	9½
White, sandy clay (No. 3002)	5
Grayish blue, carbonaceous, sandy clay (No. 3003)	2½
Bluish gray, carbonaceous, shaly clay (No. 3004)	8
Dark blue to black, carbonaceous, shaly clay (No. 3005)	3
Thin coal seams and impure clay and sand	5
Dark blue to black, carbonaceous, shaly clay	15

Sample No. 3001 is a very compact, structureless clay, the body being fairly fine, but the clay contains much sand, which is fine and quite pure silica; mica, carbonaceous, and ferruginous particles are present to a slight extent. The test piece slaked in two hours. With 22.5 per cent. of tempering water the clay developed a good plasticity, although it did not adhere very well. It had an air shrinkage of 7.3 per cent, a tensile strength of only 70 pounds, and checked somewhat on drying. The results of the burning tests were as follows:

	Cone 05	Cone 03	Cone 01	Cone 5	Cone 10
Fire shrinkage	1.0 per ct.	1.9 per ct.	2.4 per ct.	4.8 per ct.	4.4 per ct.
Color	light pink	light yellow	yellow	cream white	cream white
Absorption		13.4 per ct.		3.8 per ct.	3.9 per ct.

The clay was incipiently fused at cone 5, but not vitrified until cone 14, when it gave a dense, light gray, body. Viscosity took place at cone 24. The bricklets were strong and did not check any further on burning.

Care would have to be taken in drying this clay, and probably it could not be used alone for the manufacture of stoneware or earthenware. It might be used by the dry-press process for the manufacture of brick, but would give a stronger brick by the plastic process.

Sample No. 3002 was a compact and massive clay, somewhat laminated in color and texture. The color is a cream white, stained reddish and brown by ferruginous and carbonaceous material. The material has a very fine, smooth, white clay body, but contains much fine sand. The clay is prepared very easily. The plasticity was good with 25.6 per cent. of tempering water. The air shrinkage was 7.0 per cent., the tensile strength 106 pounds, and the clay dried without checking. Its behavior in burning is shown below:

	Cone 05	Cone 03	Cone 5	Cone 10
Fire shrinkage	0.7 per ct.	2.7 per ct.	7.5 per ct.	7.0 per ct.
Color	buff	buff	gray	gray
Absorption		14.0 per ct.	1.4 per ct.	0.3 per ct.

The bricklets were strong and dense and were good except the one to cone 10, which cracked a little. Incipient fusion took place at cone 2, vitrification at 11, and viscosity at 20. The clay fusibility cones when heated above cone 15 were mottled, gray and dark brown. This clay is not suitable for white ware, but the cheaper grades of stoneware could be manufactured from it. It could also be used for pressed brick and terra cotta, and possibly vitrified wares, such as paving brick.

No. 3004 was also tested. This is a compact shaly clay which has hardened somewhat. It contains considerable grit but the clay body is fine. It also has many carbonaceous and some ferruginous partings and patches. It slaked in an hour and a half. It worked up to a good plasticity, although rather sticky, with 26.2 per cent. of water. The air shrinkage was 6.1 per cent. and the tensile strength 103 pounds. It showed a tendency to check a little on drying. Its burning tests were as follows:

	Cone 05	Cone 03	Cone 01	Cone 5	Cone 10
Fire shrinkage	1.7 per ct.	2.3 per ct.	4.8 per ct.	8.4 per ct.	failed by swelling
Color	cream	cream white	cream white	light gray	grayish white
Absorption		14.9 per ct.	9.9 per ct.	0.6 per ct.	

The clay was incipiently fused at cone 1, vitrified at cone 6, and rendered viscous at cone 18. The bricklets were strong, but checked a little during burning.

This clay would have to be used at low temperatures, below 2300 degrees F. It could doubtless be employed for light colored brick and if the shrinkage was held up by fine grogging or mixing with other clays, for cheap grades of unglazed earthenware.

The bottom clay in this section appears to be similar to the last clay described.

Clays are reported near Antelope, to the east and south of the track. Young Man's butte, between Antelope and Richardton, rises above the clay horizon and is capped by calcareous sandstone. No good clays were seen outcropping in the butte or in the immediate neighborhood, but the exposures were not good and clay may occur there.

From Taylor to Dickinson, north of the railroad, occurs a more or less continuous series of clay outcrops. The only important break is at Gladstone, where the Green river cuts through this divide between the Heart and Knife river drainages. West of Gladstone the clay outcrops in the high divide between the Heart and Green rivers. South of the track but little clay is exposed except along the Heart river southeast of Gladstone, in the high buttes bordering the valley.

Northeast of Taylor about a mile and a half, in the hills on the edge of the deep valley to the north, this section is shown:

	Feet.
Sand (Nos. 3301-2)	10
White, somewhat sandy clay	6
Sand	3
Hard sandstone	2
White, sandy, calcareous clay (No. 3303)	3
Hard sandy layer, forms cap of projecting ridges	2
Fine, white, sandy clay (No. 3304)	4
Ferruginous sand	10
Hard sandy clay, capping projecting layers	2
White, fine, sandy clays, contains a little lime (No. 3305)	6
Sand or unexposed	60

The sandy clay layers are practically one, the ferruginous sandy layers and the hard layers being only developed locally. These hard sandy clays are quite common and are probably formed by exposure to the weather. The clay becomes baked, and the grains are cemented together with lime or secondary silica.

Sample No. 3302 is a compact clay with a pure white, fine clay body, with considerable fine sand and a few small iron segregations, staining the clay red. It is soft and slakes very easily. With 26.7 per cent. of water it was tempered to its best plasticity, which was only moderate. The air shrinkage was 5.9 per cent., the tensile strength 133 pounds, and there was no sign of checking on drying. It burned as follows:

	Cone 05	Cone 03	Cone 01	Cone 5	Cone 10
Fire shrinkage	2.2 per ct.	2.4 per ct.	3.3 per ct.	6.5 per ct.	6.9 per ct.
Color	buff	cream	cream	gray	light gray
Absorption		13.6 per ct.	12.0 per ct.	5.7 per ct.	2.2 per ct.

The clay was fused incipiently at cone 4, vitrified at cone 12, and viscous at 21. The bricklets were strong, and although the one to cone 10 was cracked a very little, the others were not checked at all.

The clay of No. 3304 is compact, the clay body being extremely fine. Some fine sand is present and more or less carbonaceous material. An analysis shows it to have the following composition:

	Per Cent.
Silica	65.46
Alumina	20.97
Ferric oxide	1.83
Lime	0.23
Magnesia	1.14
Soda	0.72
Potash	1.38
Volatile matter	6.79
	98.52

The clay slaked almost immediately, and was tempered to a good plasticity with 27.9 per cent. of water. It has an air shrinkage of 5.2 per cent., a tensile strength of 91 pounds, and showed but very little tendency to check. Its behavior in burning is shown below:

	Cone 05	Cone 03	Cone 01	Cone 5	Cone 10
Fire shrinkage	1.8 per ct.	2.4 per ct.	2.4 per ct.	8.2 per ct	8.3 per ct.
Color	cream	cream	cream white	cream	light gray
Absorption		17.2 per ct.		4.7 per ct	1.1 per ct.

It is incipiently fused at cone 4 and vitrified at cone 15, giving an almost white, dense body. It is not made viscous until a temperature some over cone 25 has been reached.

It is probable that these clays could be used for stoneware, such as jars, jugs, sewer pipe, etc., and low grade cream colored earthenware. The second is not sufficiently refractory to be considered a good fire clay, as will appear from an examination of the chemical analysis and the fusion tests, which agree.

West of Taylor these same clays are seen north of the track. One outcrop about one and a quarter miles west shows the following section:

	Feet.
Hardened clay	1
White sandy clay, similar to No. 3304 above, but is coarser and contains more sand. The upper part is more plastic and firmer..	10
Ferruginous sand	5

About two miles northeast of Gladstone the following section is exposed:

	Feet.
Hardened clay	½
White, very fine, smooth, pure clay, sandy and impure near the top, (No. 3501)	3
White clay, somewhat sandy, otherwise very pure, (No. 3502)	3
Impure, ferruginous, sandy clay	2
White, sandy clay	8
Ferruginous sand	4

About 15 feet higher and 200 yards to the west of the above outcrop is exposed three or four feet of clay similar to No. 3502. These clays lie some 125 feet above the town of Gladstone, at an elevation of 2480 feet above sea level.

A sample from No. 3502 was tested. It is a strong, compact, somewhat shaly clay. The body is a very fine, smooth, pure white clay, mixed with a good deal of fine silica. An analysis shows the following composition:

	Per Cent.
Silica	65.64
Alumina	22.74
Ferric oxide	1.66
Lime	0.29
Magnesia	0.61
Soda	1.76
Potash	1.46
Volatile	6.15

It slaked almost immediately, and with 26.7 per cent. of water developed a good plasticity. The air shrinkage was 5.0 per cent., the tensile strength 80 pounds, and it dried without cracking. It burned as follows:

	Cone 05	Cone 01	Cone 5	Cone 10
Fire shrinkage	0.8 per ct.	3.3 per ct.	6.9 per ct.	8.9 per ct.
Color	pinkish white	cream white	cream white	gray white
Absorption		14.1 per ct.	6.1 per ct.	1.8 per ct.

The bricklets were strong and showed but little tendency to crack in burning. The clay fused incipiently at cone 3 and vitrified at cone 10, giving a very dense creamy white body without cracks. It was not made viscous at cone 25. Such a clay is useful for stoneware and brick.

These clays were found to extend north along the divide east of the Green river for several miles. Eight to ten miles northeast of Gladstone on the northeastern side of the divide, the badlands at

the headwaters of Deep creek exhibit from 40 to 60 feet of these same clays, mostly sandy and high in silica, but some are quite pure. These badlands are called "The Fairy Dells," and quite appropriately, the dark green evergreens lining the bottom standing out in strong contrast against the blinding whiteness of the sandy clay banks. (See Plate I.)

A cliff on section 25, T. 141, R. 95, exposes the following:

	Feet.	Inches.
Yellow ferruginous sand..................................	10	
Light yellowish gray, fine-grained clay, contains considerable ferruginous and carbonaceous material, and is also calcareous, (No. 2601)...............................		10
Lignite..............		2
Dark, carbonaceous, impure clay, grows lighter downward..	1	6
Dark, carbonaceous, sandy clay, lighter colored than above..	1	
Yellowish white, somewhat sandy clay, (No. 2602).........	3	
Buff clay, very smooth, and with but little sand, stained yellow and reddish with iron, (No. 2603).............	2	
White clay, (No. 2604)..................................	3	
White, sandy clay, very pure, (No. 2605-6)................	5	
Light grayish clay, like overlying strata, (No. 2607)........	1	6
White, sandy clay of great uniformity, except for an occasional thin layer stained with iron, (No. 2608-9).......25 to 30		

No. 2602 is a very fine white clay, compact and structureless, in which there is, however, more or less sandy material. The sand is composed of fine quartz grains, and the clay is quite free from ferruginous or carbonaceous material. It slaked very easily, and with 25.5 per cent. of tempering water the clay was brought to a good plasticity. The air shrinkage was 5.4 per cent., the tensile strength 70 pounds, and the clay dried without checking. It burned as follows:

	Cone 05	Cone 1	Cone 5	Cone 10
Fire shrinkage	2.3 per ct.	6.9 per ct.	9.3 per ct.	7.2 per ct.
Color	cream	light buff	gray	gray white
Absorption			0.4 per ct.	0.9 per ct

The bricklets were very strong and dense. The one burned to cone 5 was cracked a very little, and the one to cone 10 warped and swelled a trifle. Incipient fusion occurred at cone 1 and vitrification at cone 9, but the clay did not become viscous until cone 24.

The clay of No. 2604 is compact and structureless with very little grittiness and is mostly a very fine, smooth, white clay. It took 25.7 per cent. of water to temper it to its best plasticity, which was very

good. The air shrinkage was 5.0 per cent. and the tensile strength 104 pounds. The clay did not crack on drying. Its behavior when burned is shown below:

	Cone 05	Cone 1.0	Cone 5	Cone 10
Fire shrinkage	1.8 per ct.	3.8 per ct.	6.5 per ct.	6.9 per ct.
Color	white	white	cream	white
Absorption			5.8 per ct.	0.6 per ct.

The clay was fused incipiently at cone 5 and vitrified at cone 10, but did not become viscous until cone 24, fusing to a white enamel. The burned clay was strong and little trouble was experienced in burning, due to checking. A clay of this character could be used for pressed or repressed brick, sewer pipe, stoneware, etc. It is also an excellent modelling clay.

The light grayish, sandy clay (No. 2607) contains a large amount of clay material and very fine, pure quartz sand, with a little mica. It is quite free from iron and is colored with carbon. It has a good plasticity when tempered with 23.1 per cent. of water. The air shrinkage was 3.5 per cent., and the tensile strength 86 pounds. The clay dried without checking. The results of the burning tests were:

	Cone 05	Cone 1	Cone 5	Cone 10
Fire shrinkage	0.8 per ct.	2.3 per ct.	4.4 per ct.	6.8 per ct.
Color	white	white	cream	white
Absorption			10.6 per ct.	1.5 per ct.

The clay was incipiently fused at cone 9, at cone 15 was completely vitrified and was burned to a pure white, dense body. It was not viscous at cone 25.

The following is an analysis of this clay:

	Per Cent.
Silica	70.27
Alumina	20.81
Ferric oxide	0.33
Lime	0.23
Magnesia	0.26
Volatile matter	6.38

It is good refractory clay, and might also be used for whiteware if it could be freed from its sand.

The white sandy clay (No. 2608) is mostly a fine pure quartz sand, the individual grains being covered with a very fine, pure, white clay. The composition is as follows:

	Per Cent.
Silica	75.65
Alumina	17.85
Ferric oxide	0.49
Lime	0.23
Magnesia	0.18
Soda	trace
Potash	0.88
Volatile matter	5.31

It became moderately plastic with 19.0 per cent. of tempering water. The air shrinkage was only 1.5 per cent. and the tensile strength but 40 pounds. It dried without cracking. The results of the burning tests were:

	Cone 05	Cone 1	Cone 5	Cone 10
Fire shrinkage	0.3 per ct.	0.0 per ct.	1.3 per ct.	1.8 per ct.
Color	pink white	white	cream white	white
Absorption	18.05 per ct.		14 5 per ct.	11.6 per ct.

The bricklets were not strong until burned to cone 5 or 10. This clay was not even incipiently fused at cone 25.

This is an excellent fire clay. It would probably have to be worked by the wet-mud process for the best results. A great variety of fire clay products could be made from it.

A sample (No. 2610), furnished by Mr. Cryne of Gladstone from section 3, T. 140, R. 95, several miles southeast of the outcrop just described, is very much like the last two clays described, and is about intermediate between the two in its properties. It became more plastic than No. 2608, nearly as much so as No. 2607, when tempered with 22.8 per cent. of water. It had an air shrinkage of 2.9 per cent., a tensile strength of 83 pounds, and dried without checking. The results of the burning tests were as follows:

	Cone 05	Cone 1	Cone 5	Cone 10
Fire shrinkage	0.2 per ct.	1.8 per ct.	3.0 per ct.	6.8 per ct.
Color	pink white	white	cream white	white
Absorption			14.5 per ct.	3.7 per ct.

The bricklets were strong, and were not checked in burning. The clay was incipiently fused at cone 12, but was not vitrified at cone 25.

This is a low grade fire clay. It could be worked by the stiff-mud process.

Outcrop of the white Tertiary clays between Gladstone and Dickinson, north of railroad.

Southeast of Gladstone the buttes on the east side of the Heart river valley are capped with 30 feet or more of white sandy clay, which appears to be very similar to the above sample (No. 2607).

Between Gladstone and Dickinson and north of the railroad are many clay outcrops. An exposure on top of one of the buttes about six miles from Dickinson, and between two and three miles north of the track, exhibits the following section:

	Feet.
Hard sandy clay	1
Fine, sandy clay, grading into the beds below, (No. 2401)	2½
Very fine, smooth clay, (Nos. 2402-3-5)	5
Sandy and ferruginous clay, growing more sandy and impure downwards, (No. 2404)	1

This clay is not confined to this one butte but outcrops on the tops of neighboring buttes, and doubtless also occurs in the range of buttes just to the north and in the Davis buttes to the northwest.

No. 2401 is a compact, structureless clay, with a fine clay body, but with a good deal of very fine, pure quartz sand and also a little mica. It is grayish white in color, and is stained very little with iron. An analysis shows:

	Per Cent.
Silica	75.27
Alumina	17.29
Ferric oxide	0.83
Lime	0.46
Magnesia	0.18
Soda	trace
Potash	0.32
Volatile matter	5.75

It became very plastic when tempered with 22.1 per cent. of water. It shrank on air drying 5.0 per cent. and did not check. The tensile strength was 141 pounds. The results of burning were as follows:

	Cone 05	Cone 1	Cone 5	Cone 10
Fire shrinkage	0.0 per ct.	1.7 per ct.	5.3 per ct.	5.0 per ct.
Color	orange	yellow	buff	yellow and gray
Absorption			4.7 per ct.	3.4 per ct.

The bricklets were all strong and did not crack on burning. The clay was incipiently fused at cone 7, and vitrified at cone 16, burning to a grayish white, dense body which did not swell or crack. It did not become viscous at cone 25.

This clay is refractory and useful as a fire clay. It is rather too refractory for ordinary stoneware but on being washed would make excellent material for white earthenware and other forms of pottery.

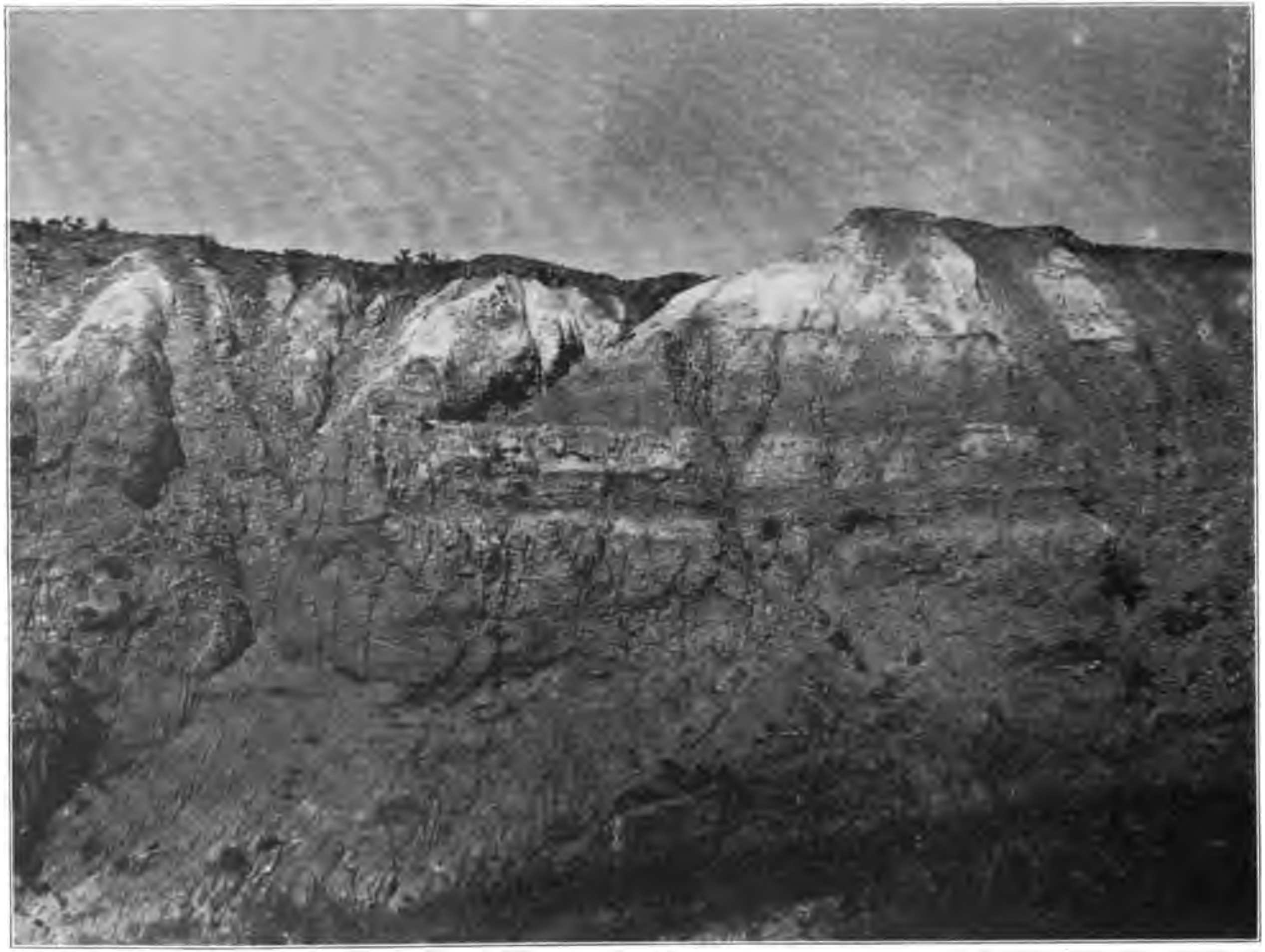
Three samples from the 5-foot layer were tested; No. 2402 from near the top, No. 2403 near the bottom, and No. 2405, a selected sample, from an outcrop 50 feet to the west. The clay is very uniform in character. It is compact, structureless, of a fine pure clay body, showing little or no grittiness between the teeth. It is grayish white to white in color, the gray color being due to carbon. Some of the surfaces are somewhat stained by iron, but it appears to be very pure.

Analyses of Nos. 2402 and 2403 show the following composition:

	No. 2402.	No. 2403.
Silica	65.70	65.03
Alumina	22.07	23.16
Ferric oxide	1.33	1.00
Lime	0.23	0.29
Magnesia	0.26	0.44
Volatile	6.90	7.21

The physical tests are shown in the following table:

	No. 2402	No. 2403	No. 2405
Water required	27.3 per cent	32.3 per cent	35.0 per cent
Plasticity	good	good	very good
Air shrinkage	5.6 per cent	6.5 per cent	7.0 per cent
Tensile strength	151	161	177
Cone 05—			
Fire shrinkage	1.8 per cent	2.2 per cent	3.3 per cent
Color	orange	pink white	pink white
Cone 1—			
Fire shrinkage	6.3 per cent	6.8 per cent	8.2 per cent
Color	buff	cream white	cream white
	steel hard	steel hard	steel hard
Cone 5—			
Fire shrinkage	7.7 per cent	8.3 per cent	9.3 per cent
Color	gray	buff white	gray white
Absorption	0.4 per cent	2.9 per cent	1.2 per cent
Cone 10—			
Fire shrinkage	failed by swelling a little	8.5 per cent	9.0 per cent
Color	gray	grayish white	grayish white
Absorption	1.0 per cent	0.3 per cent	0.4 per cent
Incipient fusion	Cone 1	Cone 3	Cone 1
Vitrification	Cone 7	Cone 11	Cone 8
Viscosity	Cone 23	Cone 26	Cone 26



Clay beds exposed on Heart river one mile south of Dickinson. The white, high grade Tertiary clays are shown at the top of the bluff.

The bricklets were all strong; sample No. 2402 shows a tendency to swell and warp at high temperatures. The others burned dense and white even at very high temperatures, and did not warp or crack.

This clay is most suitable for stoneware, pressed brick, etc., burning dense at low temperatures. The lower part, at least, could also be utilized for white earthenware. These clays are very easily worked by the plastic process.

These clays are representative of the more plastic ones of this neighborhood, which extend south of Dickinson and also to the north. In the exposure just described the underlying white sandy fire clays are not well exhibited but doubtless exist.

At the clay pits of the Dickinson Pressed and Fire Brick Company is shown a very complete section. These pits are situated about a mile southwest of Dickinson on sections 8, 9, 16 and 17, in a butte which rises about 100 feet above the Heart river, the latter flowing by the northern base of the butte. The bluff of the river exposes the following section:

	Feet.	Inches.
Hardened sandy clay	1	6
White, fine grained, sandy clay, bottom marked by a rusty streak 2 or 3 inches thick, (Nos. 101-2-3)	10	
Light grayish or bluish clay, (No. 104)	2	
Grayish blue, carbonaceous clay, is more ferruginous near the base, (Nos. 105-6)	5	
Fine grained, yellow, ferruginous sand, grows impure downwards	8	
Impure, sandy clay shale	3	
Yellow sand, with thin lignite layers near the base	34	
Blue clay		8
Lignite	1	6
Blue clay	2	
Lignite		4
Clay, grading into sand	10	
Lignite, poor and sandy, changes into ferruginous sand, and also contains some clay partings	3	
Sand, with many impure, ferruginous concretions, partly unexposed to creek bottom	30	

The upper part of this section is classed as Tertiary and the bottom as Laramie or possibly Fort Union. The dividing line is doubtful, but is probably somewhere near the base of the 34-foot layer of sand underlying the clays.

A peculiar feature was noticed here. Underlying the plastic clays at the southwest end of the butte is a white, sandy fire clay

used for fire brick. The 8-foot layer of ferruginous sand, noted in the section above, passes into this pure sandy clay. The change is quite abrupt. Some 200 yards west, along the face of the bank, from the point where the above section was taken, the upper part of the 8-foot layer of sand (sample No. 109) becomes lighter colored and contains less iron and more clayey material. South of this point about 150 yards, on section 17, 8 feet of pure white, sandy clay is exposed (sample No. 111). This is like No. 109 in structure and texture, but it is much purer. The sand grains are nearly all pure quartz, but a few micaceous and black grains are present. Coating the sand grains is a pure white clay, so that the material becomes moderately plastic when wet.

Analyses of these clays are shown in the following table:

	No. 101[1]	No. 104[1]	No. 105	No. 111
Silica	72.66	64.84	66.55	73.20
Alumina	17.33	24.31	23.22	18.56
Ferric oxide	1.05	1.60	1.16	0.50
Lime	0.13	0.11	0.29	0.29
Magnesia	.....	0.24	0.61	0.52
Potash	0.36	trace	.....	0.38
Soda	0.38	0.32	.....	0.36
Volatile matter	9.35	8.58	7.09	5.93

The upper 10 feet is a very fine-grained, compact, structureless clay. Sample No. 101 from near the top contains a few coarser particles, which give the clay a gritty feel. The sand is nearly pure quartz, although a little mica is also present. Near the bottom (No. 103) the coarse grains and mica scales are more abundant, which give the clay something of a laminated appearance. The clay is also stained reddish and yellowish in places, although it is mostly a pure white, with a few gray carbonaceous spots.

Sample No. 104 is even finer grained and contains scarcely any grit which can be detected between the teeth. It is somewhat darker in color, containing more carbon.

Sample No. 105, from near the top of the 5-foot layer of grayish blue clay, is also compact, structureless, and fine grained. It contains very little more grit than does No. 104. It is carbonaceous and shows fossil leaves. Near the base it grows rather sandy and more impure.

All of these clays are soft and can be easily dug. They are also easily prepared. Their physical properties are shown in the following table:

[1] E. J. Babcock; N. Dak. Geol. Survey, Vol. I, p. 55.

	No. 101	No. 103	No. 104	No. 105	No. 111
Water required	25.9 per ct.	27.7 per ct.	25.2 per ct.	24.9 per ct.	22.6 per ct.
Plasticity	very good	very good	very good	very good	moderate
Air shrinkage	4.4 per ct.	3.0 per ct.	4.7 per ct.	4.6 per ct.	2.0 per ct.
Tensile strength	94 lbs.	160 lbs.	138 lbs.	187 lbs.	90 lbs.
Dried	without checking	without checking	slight tendency to check		without checking
CONE 05—					
Fire shrinkage	0 8 per ct.	0.5 per ct.	1.0 per ct.	1.0 per ct.	0 3 per ct.
Color	pink white	pink white	light pink	pink	pinkish white
Absorption					19.8 per ct.
CONE 1—					
Fire shrinkage	4.7 per ct.	3.6 per ct.	6.0 per ct.	5.4 per ct.	0 9 per ct.
Color	light buff	light buff	very light buff	light buff	cream white
CONE 5—					
Fire shrinkage	6.7 per ct.	5.8 per ct.	6.6 per ct.	7.2 per ct.	2.0 per ct.
Color	light buff	white	gray white	light gray	white
Absorption	5.1 per ct.	8.0 per ct.	2 4 per ct.	4.7 per ct.	14.1 per ct.
CONE 10—					
Fire shrinkage	6.0 per ct.	7.3 per ct.	9.0 per ct.	7.7 per ct.	2.5 per ct.
Color	light gray	gray white	white	gray white	white
Absorption	2.1 per ct.	2.6 per ct.	0.5 per ct.	3.0 per ct.	13.1 per ct.
Incipient fusion	Cone 7	Cone 8	Cone 3	Cone 7	unaffected at cone
Vitrification	Cone 18	Cone 17	Cone 12	Cone 14	Cone 25
Viscosity	Cone 25	Cone 25 (edges rounded)	Cone 25	Cone 22	

Most of the bricklets were strong and showed little tendency to swell or crack. No. 101 cracked and warped a little when burned above cone 7. Nos. 103 and 104 burned to dense strong bricklets and did not check or swell at all. No. 105 when burned to cone 10 cracked somewhat. Sample No. 111 did not check at all, but did not burn dense even at cone 25, but the bricklets when burned to cone 5 or above were strong.

These clays are at present used for dry-press and fire brick, which are both of good quality. They are particularly adapted, except sample No. 111, to a plastic (stiff-mud) process. High grade stoneware and white earthenware can be manufactrued from the plastic clays, which would be improved by washing. Sample No. 111 is an excellent fire clay.

The overlying hardened clay is ground and used for grog. A similar hardened clay, found a few miles north of Dickinson (No. 4801), was burned; it had no air shrinkage and was unaffected at

cone 25. It burns buff, however, and probably could not be used in the manufacture of stoneware.

Similar clays outcrop north of Dickinson. About four miles northeast, between the southernmost and the central buttes of the range of Davis buttes, the following section was taken:

	Feet.
Hardened clay, (No. 4801)	½
White, fine grained, sandy clay, (No. 4802)	6
White sandy clay, (No. 4803)	3

The upper clay (No. 4802) is much like the upper fire clay at the Dickinson pits. It is compact, structureless, mostly a fine pure white clay, but with a good deal of fine sand. It required 29.6 per cent. of water to temper it to its best plastictity, which was good. It had an air shrinkage of 6.5 per cent., a tensile strength of 138 pounds, and dried without checking. Its behavior in burning was as follows:

	Cone 05	Cone 03	Cone 5	Cone 10
Fire shrinkage	1.7 per ct.	2.4 per ct.	7.5 per ct.	8.2 per ct.
Color	light pink	light pink	light gray	gray white
Absorption		16.8 per ct.	2.6 per ct.	1.3 per ct.

There was no tendency for the bricks to warp or crack, but they burned to a hard, strong, dense body. The clay was incipiently fused at cone 3, vitrified at cone 12, and became somewhat viscous at cone 25. This clay, although not such a good fire clay as that at Dickinson, is suitable for the manufacture of stoneware.

The underlying clay (No. 4803) contains more sand and is very soft and friable, like the white, sandy, bottom clays (No. 111) at the Dickinson pits. It is, however, finer and contains more clayey material and its plasticity was good to moderate when tempered with 31.6 per cent. of water. The air shrinkage was 4.0 per cent. and the tensile strength 52 pounds. The clay did not check on drying. The burning tests gave the following results:

	Cone 01	Cone 03	Cone 5	Cone 10
Fire shrinkage	0.3 per ct.	0.7 per ct.	2.3 per ct.	3.2 per ct.
Color	buff white	buff white	white	white
Absorption			16.3 per ct.	15.7 per ct.

The bricklets burned to cones 5 and 10 were strong and did not crack. The clay was incipiently fused at cone 12, but was not vitrified at cone 25.

The principal use for a material of this character is as a fire clay, it being very refractory. The moderate plasticity, weak tensile strength and porosity of burned ware are not desirabble qualities for the manufacture of earthenware or stoneware.

These beds are traceable still further north. At the extreme northern end of the range of Davis buttes, on the north side of the Green river and some seven miles northeast of Dickinson, the following section is exhibited:

	Feet.
Sandstone quite well consolidated, quarried on the top of the butte..	50
Sand, usually ferruginous and unconsolidated, one or two impure layers of ferruginous, sandy clay........................	70
Fine, white, sandy clay, stained with iron near the bottom, (No. 2501)	8
Smooth, white clay, (No. 2502)........................ ...	3
White, sandy clay..	2
Dark, carbonaceous, sandy clay........................	½
White, sandy clay, becomes ferruginous downwards...............	3
Unexposed or ferruginous sand........................	40
Laramie sand and impure clays, and 2 or 3 very thin lignite seams to river bottom..	45

No. 2501 is a rather fine quartz sand, with a little clay body, so that it is very friable. It contains some mica and also a little calcium carbonate. It is grayish white in color, but the weathered surfaces are stained yellow with iron. It slaked very easily, and with 24.6 per cent. of water was tempered to a good plasticity. The air shrinkage was 5.0 per cent. and the tensile strength 157 pounds. The clay dried without any signs of failure. It burned as follows:

	Cone 05	Cone 1	Cone 5	Cone 10
Fire shrinkage	0.4 per ct.	1.7 per ct.	4.5 per ct.	5.5 per ct.
Color	pink white	buff	buff	buff
Absorption			8.6 per ct.	3.3 per ct.

The bricklets were strong, and were not cracked or warped. The clay was not incipiently fused until cone 9; it was vitrified at cone 14, and at cone 24 was viscous.

The clay did not burn dense enough at a low temperature to be used for cheap stoneware, and it is not suited for white ware. It is, however, good for front bricks and terra cotta.

The clay below (No. 2502) is a very fine grained clay with no grit which can be detected between the teeth. It is compact, but somewhat shaly and jointed. It is light gray to white in color, stained yellowish or red on the joint surfaces. It slaked easily. With 30.2

per cent. of water it developed a very good plasticity. It shrank on drying 5.3 per cent. and did not check. The tensile strength was 175 pounds. On burning the following results were obtained:

	Cone 05	Cone 1	Cone 5	Cone 10
Fire shrinkage	0.8 per ct.	7.7 per ct.	9.4 per ct.	failed by warping
Color	pink white	buff white	light gray	gray white
Absorption			0.4 per ct.	

The bricklets burned at temperatures less than cone 10 were very strong and dense and were not cracked or warped. The clay was incipiently fused at cone 01, vitrified at cone 6, and became viscous at cone 19.

Because of its dense burning qualities at low temperatures this clay would probably make an excellent material for stoneware. It is not refractory enough for the better grades of ware. A material like this might also be used for a good grade of paving brick.

West of Dickinson no clays were seen near the railroad, although the general elevation of the country is high enough. Instead, coal outcrops at elevations of 2,500 feet and more above sea level, and the associated clays are of low grade, like the ordinary Laramie coal clays.

Southwest of Dickinson there are several ranges of buttes which appear white from a distance and seem to contain considerable clay. They are, however, composed principally of calcareous sands which weather white. Near the base of these buttes is a horizon of clay of rather low refractiveness, which probably corresponds with the higher grade clays further east, occurring at the same elevation.

A low butte about nine miles southwest of Dickinson, but only about three and a half miles from the railroad, shows the following section:

	Feet.
Hard sandstone cemented with lime carbonate	2
White weathering sand, highly calcareous, and probably rich in alkalies	8
Hard sandstone grading into softer layers below, contains considerable lime and weathers white	10
Yellow, ferruginous sand grading into an impure clay at the bottom	10
Dark, olive-gray, sandy clay, calcareous, and contains gypsum (No. 801)	3
Bluish gray, fine grained, sandy clay, quite calcareous (No. 802)	4
Lignite seam	⅓
Light bluish gray clay, somewhat calcareous (No. 803)	1
A light grayish white clay, slightly calcareous (No. 804)	5
Yellow, ferruginous sand to creek bottom	8

No. 802 is a clay much like the overlying three feet, but is somewhat purer. It is a compact structureless clay and consists mostly of fine sand, mica and quartz grains, with a fine clay body. It contains impure iron segregations which show as red spots through the clay, and it is also carbonaceous and calcareous. It slaked easily, and with 27.8 per cent. of water was tempered to a good plasticity. The air shrinkage was 7.3 per cent., and the tensile strength 300 pounds. This high tensile strength may be due to the presence of soluble salts. The clay did not check on drying. The following shows the burning qualities:

	Cone 03	Cone 1	Cone 5
Fire shrinkage	4.8 per ct.	3.8 per ct.	failed by bloating
Color	red	dark red	dark brown
Absorption	4.7 per ct.	4.3 per ct.	

Incipient fusion occurred at cone 04, vitrification at cone 5, and viscosity at cone 14, it fusing to a greenish gray pumice. The bricklets burned to cone 03 and 1 were strong and were not checked or warped. They had, however, a black core, probably due to the reducing action of the sulphur.

This clay is not valuable but might be utilized for red brick. Trouble in burning is likely to be encountered on account of the sulphur present.

Samples Nos. 803 and 804 are very much alike, although the latter appears to be a little purer. They are compact, structureless clays, with a very fine, smooth clay body. They contain enough fine sand to give them a sandy feel. The clay is grayish white to white, but is spotted with iron and carbonaceous material. An analysis of No. 803 shows the following composition:

	Per Cent.
Silicia	66.48
Alumina	19.55
Ferric oxide	2.49
Lime	0.84
Magnesia	1.16
Volatile matter	7.45

No. 803 required 27.0 per cent. of tempering water to bring it up to its best plasticity, which was good. It had an air shrinkage of 7.6 per cent., a tensile strength of 226 pounds, but showed an inclination to check on drying. It burned as follows:

	Cone 010	Cone 05	Cone 03
Fire shrinkage	1.4 per ct.	4.4 per ct.	cracked badly and swelled
Color	orange	red orange	orange with bronze vitrified surfaces
Absorption	12.8 per ct.	7.1 per ct.	

The clay fused incipiently at 04, vitrified at cone 3, and became viscous at cone 12. This is only suitable for work at very low temperatures, but a good, strong brick can be made from it.

The lower clay (No. 804) worked up easily, and with 21.6 per cent. of water was tempered to a good plasticity. It had an air shrinkage of 5.3 per cent., a tensile strength of 206 pounds, and dried without checking. The results of the burning tests were:

	Cone 03	Cone 1	Cone 5
Fire shrinkage	2.7 per ct.	2.9 per ct.	4.8 per ct.
Color	orange yellow	yellow	red to greenish
Absorption		7.2 per ct.	3.7 per ct.

The bricklets were very strong and did not crack or warp on burning. Incipient fusion occurred at cone 1, vitrification at 8, and viscosity at cone 16.

A clay of this character would be useful for ordinary brick and cheap grades of hollow structural material.

It will thus be seen that different kinds of clay, suitable for a great variety of uses, occur in great abundance near or within a few miles of the Northern Pacific track between Hebron and three or four miles west of Dickinson. These clays have been developed somewhat, but the value of some of the high grade stoneware and earthenware clays has not yet been realized.

Clays North of the Northern Pacific Railroad. The Tertiary clays outcrop very plentifully north of the railroad. They underlie the largest area in the neighborhood of the Killdeer Mountains, extending eastward from Oakdale 30 or 35 miles, the longest north and south dimension being some 10 or 12 miles.

An outcrop on the south side of the Killdeers, near the base, shows the following strata:

	Feet.
Ferruginous sand	10
Dark, bluish gray, carbonaceous clay (No. 3801)	2
White clay (No. 3802)	3
Impure sandy lignite	1
Grayish white, sandy clay (No. 3803)	2½

	Feet
Dark, sandy, carbonaceous clay	1½
Sand, quite free from iron, but little clayey material	1
Light gray, sandy clay (No. 3804)	1½
Impure sandy clay	½
Gray, carbonaceous clay (No. 3805)	6
Sand	10

The top of the south mountain rises some 500 feet above the clay outcrop. It is capped with 300 feet of a hard, thin-bedded, calcareous sandstone. Underlying the sandstone is a ferruginous, unconsolidated sand, presumably about 200 feet thick, but it is not well exposed and may contain some clay.

Sample No. 3802 is a light, grayish white clay. It is compact but somewhat laminated by bands of darker and more carbonaceous clay. It is very fine and is practically free from grit. It slaked easily, and with 28.2 per cent. of water developed its best plasticity, which was very good. The clay shrank some 6.0 per cent. and had a tensile strength of only 53 pounds, which might be due to cracks, as it checked a little during the drying. The burning tests gave the following results:

	Cone 05	Cone 1	Cone 5	Cone 10
Fire shrinkage	1.9 per ct.	5.3 per ct.	8.3 per ct.	6.3 per ct.
Color	cream white	buff	gray	light gray
Absorption		9.6 per ct.	0.5 per ct.	0.9 per ct.

The bricklets were strong and burned dense and hard, and did not swell or warp until a temperature of cone 9 or 10 was reached. Incipient fusion occurred at cone 1, vitrification at cone 7, but not until it was raised to a temperature of cone 24 did the clay become viscous.

The clay has a rather low tensile strength and also a tendency to check on drying which would prohibit its use alone except by the dry-press process. It might, however, be mixed with other clays to give it added strength and keep up the shrinkage, and then be used for stoneware and other vitrified products.

The sandy clay below (No. 3803) is quite different in its properties. It is compact but quite friable and consists of a clay body, but with considerable very fine sand. It appears to be quite free from iron and lime but contains many carbonaceous particles. It slaked readily and required 19.6 per cent. of tempering water; the resulting plasticity was good. It had an air shrinkage of 3.8 per cent., a tensile strength of 115 pounds, and dried without checking. It burned as follows:

	Cone 05	Cone 01	Cone 5	Cone 10
Fire shrinkage	0.3 per ct.	1.5 per ct.	5.5 per ct.	6.0 per ct.
Color	light pink	buff	buff	gray
Absorption		14.4 per ct.	8.9 per ct.	2.3 per ct.

The clay was incipiently fused at cone 9, vitrified at cone 15, and viscous at cone 23. The bricklets were strong, but those burned at cone 5 and cone 10 were cracked a very little.

This clay could probably be mixed with the one above to the advantage of both and be employed for common brick.

The lower carbonaceous clay (No. 3805) is much like sample No. 3802 in its characteristics. It is darker in color, but is as fine grained and contains little or no sandy material. It slaked quite readily and was tempered to a good plasticity with 26.1 per cent. of water. The tensile strength was low, 88 pounds, the air shrinkage 5.9 per cent., and the clay checked on drying. The results of the burning tests were:

	Cone 05	Cone 01	Cone 5	Cone 10
Fire shrinkage	2.7 per ct.	6.4 per ct.	8.3 per ct.	8.7 per ct.
Color	light pink	yellow	gray	gray
Absorption			1.4 per ct.	1.0 per ct.

Incipient fusion occurred at cone 1, vitrification at 10, and viscosity at cone 24. The bricks, although strong, were checked, the edges and corners being broken off.

Such a clay as the above is of a little value alone, although doubtless it could be worked by the dry-press process very satisfactorily for brick.

To the east of the Killdeers the general elevation of the divide between the Little Missouri and Spring creek is high enough to contain the Tertiary clays. It is, however, covered with drift and is a gently rolling country with few outcrops. To the north the clays are exposed in the badlands of the Little Missouri river, which has here cut its valley to a depth of 500 feet. Along the tops of the buttes the white clays outcrop from the Killdeer Mountains to Goodman valley. They are particularly well shown along Jim creek, 10 miles east of Oakdale. They are also seen capping the tops of the buttes on the north side of the Little Missouri, where they appear to extend some miles north into the Berthold Indian Reservation.

In the badlands some five miles east of Jim creek, on Manning's old ranch, the following section is shown:

Fig. 1. Tertiary beds exposed in the badlands along the Little Missouri river, at Manning's ranch.

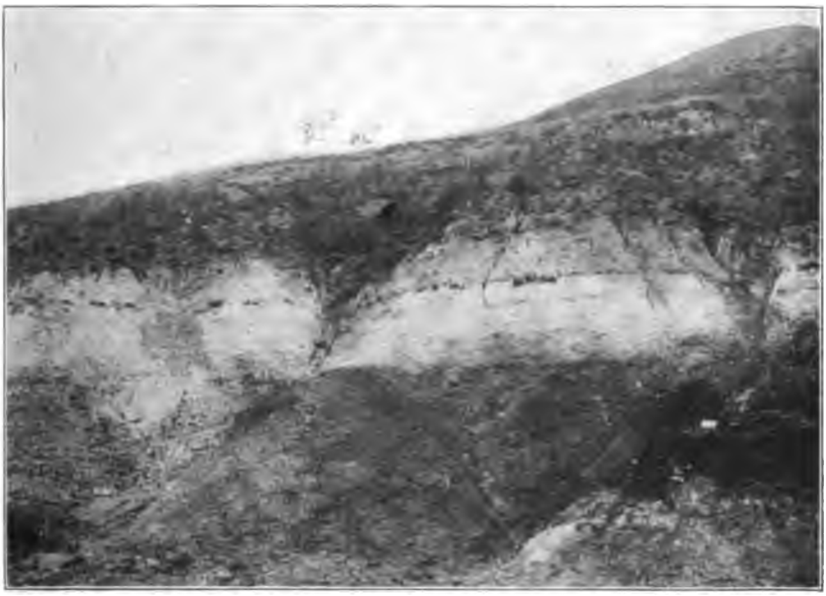


Fig. 2. Outcrop of Tertiary clays between Knife river and Spring creek, near the mail route from Rockspring to Halliday.

	Feet.
Soil and drift	5
Ferruginous sand	15
Bluish gray, sandy clay, stained purplish with iron (No. 3901)	4
Reddish clay, somewhat sandy (No. 3902)	5
Yellowish white clay, somewhat sandy, like above only less iron (No. 3903)	2
Cream colored, smooth clay, stained in streaks with iron; upper part contains a little sand, which grows less near the bottom. (Nos. 3904-5)	6
Grayish white clay (No. 3906)	4
Light grayish clay, similar to above, but is carbonaceous and somewhat shaly, due to carbonaceous partings (Nos. 3907-8)	4
Impure, lignitic, sandy clay	4
Sand, unexposed in part	100
Laramie sands, clays, and coal	400

Samples 3903, 3904 and 3906 were tested. No. 3903 is compact, structureless clay, containing considerable fine sand, a good deal of mica and segregations of iron. No. 3904 is a smoother clay with a little less sandy material, although what sand is present is coarse and is highly stained with iron. The lower clay (No. 3906) is strong and compact and contains very little grit, being mostly a very fine, white clay.

Analyses of these three clays are given below:

	No. 3903.	No. 3904.	No. 3906.
Silica	65.98	53.32	63.19
Alumina	20.68	23.76	23.35
Ferric oxide	3.82	9.30	1.49
Lime	0.29	0.25	0.29
Magnesia	0.41	1.26	0.98
Alkalies	.....	2.20	.....
Volatile matter	7.60	8.50	7.82

The alumina and silica are characteristic of the clays of this horizon, as are the fluxing constituents except iron, which in Nos. 3903 and 3904 is very high, 9.30 per cent. being the maximum for iron in all the clays analyzed for this report.

The results of the physical analyses are given in the table following:

	No. 3903	No. 3904	No. 3906
Slaking	easy	easy	easy
Water required	22.9 per cent	23.9 per cent	
Plasticity	good	good	good
Shrinkage	5.4 per cent	4.8 per cent	6.7 per cent
Tensile strength	98 lbs.	90 lbs.	100 lbs.

	No. 3903	No. 3904	No. 3906
Cone 05			
Fire shrinkage	0.5 per cent	1.7 per cent	3.0 per cent
Color	light pink	red	pink white
Absorption		13.0 per cent	14.0 per cent
Cone 01			
Fire shrinkage	6.0 per cent	2.5 per cent	4.3 per cent
Color	buff	salmon	light buff
Cone 5			
Fire shrinkage	8.3 per cent	4.7 per cent	8.7 per cent
Color	gray, spotted black	light brown	light gray
Absorption	0.5 per cent	6.1 per cent	0.2 per cent
Cone 10			
Fire shrinkage	8.0 per cent	5.9 per cent	5.7 per cent
Color	gray spotted blabk	mottled brown and black	light gray
Absorption	0.9 per cent	3.8 per cent	0.5 per cent
Incipient fusion	Cone 2	Cone 11	Cone 1
Vitrification	Cone 12	Cone 13	Cone 7
Viscosity	Cone 24	Cone 18	Cone 22

No trouble was experienced in drying or burning except with clay No. 3906, which warped and cracked after burning beyond vitrification, at cone 7.

These clays would all make good front brick either by the stiff-mud or dry-press process. Sample No. 3903 would give a dark to light gray speckled brick. From clay No. 3904 brick ranging from a salmon red to light brown, to a dark brown mottled, and finally to an almost black brick could be made, depending on the nature of the atmosphere and temperature of the kiln. This is an exceptionally good front brick clay, and very well adapted to the dry-press process. No. 3906 would not only be suitable for light colored brick, but for mixing with other clays in order to give a greater bond or density. By still further mixing, a great variety of shades could be obtained.

Nos. 3903 and 3906, which burn dense at low temperatures, might also be used for certain grades of stoneware and other vitrified products. Clay No. 3904 would not be suitable for vitrified ware, but would be for red terra cotta and hollow porous building block.

Still further to the east clays very similar to those last described outcrop along both sides of Goodman valley, a broad depression some two to three miles wide and 175 feet deep. The following section of the east bluff is exposed on section 2, T. 145, R. 90:

	Feet.
Coarse, ferruginous sand	5 to 10
Light gray, shaly clay (No. 4001)	1½
Impure, sandy lignite	2
Ferruginous sand	7
Impure, carbonaceous, sandy clay	½
Ferruginous sand	8
Sand cemented by iron, forming an impure limonite, which forms a projecting ridge	½
Light gray, sandy clay (No. 4002)	5
Impure limonite and ferruginous sand	1
Grayish white, somewhat sandy clay, stained yellow and red with iron; grows finer grained downwards (Nos. 4003-5)	10
Grayish white clay, much like above but less sandy (Nos.4006-7)	4
Grayish white, sandy clay (No. 4008)	2
Dark blue, carbonaceous clay (No. 4009)	6
Unexposed to creek bottom.	

The upper, light gray, shaly clay (No. 4001) was one of the few clays from the Tertiary horizon in this section of the state which is of very low fusibility. It is much like the clay (No. 2901) overlying the refractory clays at the Hebron Brick Company's deposit. It is of medium uniform grain, with but very little grit; it contains, however, much carbonaceous material, is highly stained in streaks with iron, and is calcareous. It slaked very easily, and with 28.5 per cent. of water was tempered to a good plasticity. It had a tensile strength of 96 pounds and an air shrinkage of 7.8 per cent., but dried without checking. It burned as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.4 per ct.	6.0 per ct.	6.2 per ct.	8.5 per ct.
Color	light red	red	dark red	dark brown
Absorption	17.4 per ct.	5.4 per ct.	4.8 per ct.	0.7 per ct.

Incipient fusion occurred at cone 06, vitrification at cone 1, and viscosity at cone 10. The bricklets all burned without checking to a dense, hard, strong body.

Although the shrinkage of this clay, both air and fire, is high, the physical tests would indicate that it would make good material for wares such as drain tile and brick. A red, common or face brick could be made and the clay would probably be admirably adapted to the dry-press process.

The clays below are more like those at Manning's ranch. Two samples (Nos. 4004 and 4005) from the 10-foot sandy layer were tested. This is a compact, structureless clay, with a very fine-

grained clay body, but also contains a good deal of fine sand. It is also stained with iron and carbon. An analysis of No. 4004 shows the following composition:

Silica	62.90
Alumina	22.68
Ferric oxide	4.98
Lime	0.32
Magnesia	0.72
Volatile matter	7.46

The physical tests are shown and compared in the table following:

	No. 4004	No. 4005
Water required	21.0 per cent	24.4 per cent
Plasticity	very good	very good
Air shrinkage	5.8 per cent	5.4 per cent
Tensile strength	84 lbs.	84 lbs.
Cone 05		
Fire shrinkage	2.9 per cent	4.0 per cent
Color	light buff	buff
Cone 03		
Fire shrinkage	3.9 per cent	4.7 per cent
Color	light buff	light buff
Absorption		9.7 per cent
Cone 01		
Fire shrinkage	3.9 per cent	6.0 per cent
Color	yellow	light buff
Absorption	7.1 per cent	7.7 per cent
Cone 5		
Fire shrinkage	7.9 per cent	7.9 per cent
Color	gray	gray
Absorption	0.3 per cent	0.3 per cent
Cone 10		
Fire shrinkage	6.9 per cent	failed by cracking
Color	mottled brown and black	mottled gray, black and brown
Absorption	0.4 per cent	1.4 per cent
Incipient fusion	Cone 1	Cone 1
Vitrification	Cone 7	Cone 6
Viscosity	Cone 20	Cone 19

The bricklets, except sample No. 4005 to cone 10, were all strong and not cracked. This clay could probably be used for several purposes, but its best use would probably be for the manufacture of front brick and tile, as the dark colors could be brought out at comparatively low temperatures by regulating the atmosphere of the kiln.

No. 4008 seems to correspond with No. 3906 from Manning's ranch. It is a compact, grayish white clay, with a very fine clay body, but with a good deal of fine quartz sand, and even a little mica.

An analysis of this clay shows the similarity with No. 3906:

	No. 4008.	No. 3906.
Silica	63.90	63.19
Alumina	25.79	23.35
Ferric oxide	1.49	1.49
Lime	0.25	0.29
Magnesia	0.25	0.98
Volatile matter	7.28	7.82

It slaked readily, and became very plastic with 28.0 per cent of tempering water. It had an air shrinkage of 5.3 per cent and a tensile strength of only 75 pounds, but the clay did not check on drying. The burning tests gave the following results:

	Cone 05	Cone 01	Cone 5	Cone 10
Fire shrinkage	1.3 per ct.	2.7 per ct.	9.0 per ct.	9.3 per ct.
Color	cream white	cream	gray white	gray white
Absorption	17.8 per ct.		0.3 per ct.	0.3 per ct.

The clay was incipiently fused at cone 3, vitrified at cone 12, and viscous at cone 25. The clay did not check or warp during burning.

This is excellent material according to the analysis and burning tests, for stoneware, light colored pressed brick, etc. The low tensile strength may be a drawback, but it could be easily improved.

South of the large area which has just been described, along the divide between Spring creek and the Knife river, are isolated outcrops of these clays. They occur in the small buttes which are found in places capping the divide. The easternmost outcrop is on the divide about four miles south of Weige's, and some eight or nine miles from the mouth of Spring creek. The top of the divide is here 300 feet above the rivers on either side. The following section is exposed by this outcrop:

	Feet.	Inches.
Ferruginous sand	10	
Impure, carbonaceous sand		8
Dark, olive gray, shaly and sandy clay, also ferruginous and carbonaceous	5	
Ferruginous sandstone (No. 4101)	1	
Impure lignite		2
Gray, carbonaceous clay (No. 4102)	3	

	Feet.	Inches.
Impure lignite	2	8
Weak, carbonaceous clay, contains gypsum	1	
Gray, carbonaceous, clayey sand (No. 4103)	4	
Impure, carbonaceous clay, contains gypsum	1	6
Impure, weak, sandy clay (No. 4104)	3	
Lignite		1
Impure, carbonaceous, sandy clay	2	
Ferruginous sand to river; near the bottom occur the Laramie clays and sands.		

The above clays are less pure than those from some of the other exposures described, but they are rather refractory and correspond in elevation and in a general way to the purer clays. Sample No. 4102 was tested and resembles No. 4008 somewhat in its physical characters. It is a structureless, compact, fine, plastic clay, with very little grittiness. It is dark colored from carbon and the surfaces are stained with a little iron. It slaked very easily and developed a very good plasticity with 30.5 per cent of tempering water. It had an air shrinkage of 6.5 per cent, a tensile strength of 106 pounds and showed but little tendency to check on drying. Its behavior during burning was as follows:

	Cone 03	Cone 01	Cone 5	Cone 10
Fire shrinkage	2.4 per ct.	4.0 per ct.	10.3 per ct.	8.0 per ct.
Color	cream	cream	gray	light gray
Absorption	17.6 per ct.	12.7 per ct.	0.5 per ct.	1.0 per ct.

The clay was incipiently fused at cone 2, vitrified at cone 7, and viscous at cone 22. The bricklets were all strong and at cone 5 burned dense without warping, but when raised above cone 7 they began to swell and warp a little.

This clay is suitable for dry-press brick, and could, by proper mixing, be used for vitrified ware by the stiff-mud process.

To the westward along the divide another outcrop was examined on the mail road from Haliday to Rockspring. It is exposed in a small butte forming the highest point of the divide in that locality, and is a little over 300 feet above the streams on either side.

The outcrop shows the following strata:

	Feet.	Inches.
Ferruginous sand	25	
Impure, sandy clay	1	6
Lignite		2
Ferruginous sand	10	
Light gray, sandy clay (No. 4401)	3	
Ferruginous sandstone		4

	Feet.	Inches.
Grayish white, sandy clay (No. 4402)	2	6
Dark gray, carbonaceous clay (No. 4403)	1	6
Gray, carbonaceous clay (Nos. 4404-5)	10	
Highly ferruginous, weak, sandy clay	8	

No. 4401 and No. 4402 are very similar in appearance, and only No. 4402 was tested. It is compact and structureless and consists mainly of a very fine, smooth clay, with a little fine quartz sand and mica. It is quite free from iron staining, the slightly grayish color being imparted by carbonaceous materials. It slaked very easily, and with 22.5 per cent of tempering water developed a good plasticity. It shrank 4.6 per cent on drying, without checking, and had a tensile strength of 79 pounds. The results of the burning were:

	Cone 03	Cone 01	Cone 5	Cone 10
Fire shrinkage	0.7 per cent	1.2 per cent	6.9 per cent	7.8 per cent
Color	cream	cream	cream	gray, speckled black
Absorption	17.2 per cent	15.7 per cent	3.9 per cent	0.7 per cent

Incipient fusion occurred at cone 5, vitrification at 11, and viscosity at 21. The bricklets were all strong and did not crack or warp when burned.

This sandy clay of rather low refractiveness is very good material for dry-pressed brick.

The carbonaceous clay below (Nos. 4403 and 4405) is quite uniform, the upper foot and a half being a little darker in color. It contains practically no sand but is a very fine, compact clay. The lower sample (No. 4405) contained a little grit and they both slaked easily. No. 4403 required 31.7 per cent of tempering water and became quite plastic. It shrank 6.7 per cent and checked and cracked considerably on drying. The tensile strength was difficult to obtain, 43 pounds being the best value. No. 4405 developed a very good plasticity with 25.5 per cent of tempering water. It shrank 6.9 per cent. on drying, but checked little, the tensile strength being 86 pounds. The results of the burning tests were:

Sample No. 4403.

	Cone 03	Cone 01	Cone 5	Cone 10
Fire shrinkage	3.5 per cent	4.9 per cent	10.2 per cent	
Color	cream	cream	gray	
Absorption	16.6 per cent	11.6 per cent	0.2 per cent	

Sample No. 4405.

Fire shrinkage	2.0 per cent	3.2 per cent	9.1 per cent	8.2 per cent
Color	cream	cream	gray	gray
Absorption	16.9 per cent	13.8 per cent	0.3 per cent	0.4 per cent

	No. 4403	No. 4405
Incipient fusion	Conc 2	Cone 3
Vitrification	Cone 6	Cone 9
Viscosity	Cone 20	Cone 21

The tendency of clay No. 4403 to check so badly, not only in drying but during the burning as well, would prohibit its use alone, at least by any plastic method. It is possible that it might be employed in the dry-press process. The other sample could doubtless be used for the cheaper grades of brick and tile.

These clays are traceable to the west and south and outcrop in more or less isolated elevations. They are also exposed south of the Knife river on the divide between Crooked creek and Green river. Two exposures, nearly due north of Dickinson, were examined; one about three miles from Crooked creek, and the other about nine miles.

The following is the section exposed on the divide nine miles from Crooked creek, and some twelve miles north by east of Dickinson:

	Feet.	Inches.
Ferruginous sand	50	
Impure, carbonaceous and ferruginous, clayey sand	7	
Impure, sandy limonite		4
Light gray clay (No. 4701)	2	6
Dark gray, carbonaceous clay (No. 4702)	1	
Light gray, sandy clay, also somewhat calcareous (No. 4703)	2	

Sample No. 4701 is a compact, very fine clay, and seemingly quite pure, but it contains a little lime. It slaked quite readily, and with 25.5 per cent of tempering water became very plastic. It had an air shrinkage of 6.1 per cent, a tensile strength of 151 pounds, and dried without checking. It burned as follows:

	Cone 05	Cone 01	Cone 5	Cone 10
Fire shrinkage	2.2 per cent	4.9 per cent	10.2 per cent	failed by warping and swelling
Color	yellow	yellow	gray	
Absorption		11.6 per cent	0.2 per cent	

Incipient fusion took place at cone 1, vitrification at cone 5, and viscosity at cone 14. The bricklets were very strong and did not

check on burning. At cone 5 the bricklet was completely vitrified and was not warped, but on raising the heat up to cone 8 or 10 the bricklet began to swell badly.

This clay might do as material for common brick and for drain tile.

The carbonaceous clay (No. 4702) is even more fusible. It is a rather fine clay with very little grit. It is, however, calcareous as well as carbonaceous. It required 27.4 per cent of tempering water, and the resulting plasticity was good, but sticky. It had an air shrinkage of 9.9 per cent, but in spite of the high shrinkage checked little on drying, the tensile strength being 166 pounds. The burning tests were as follows:

	Cone 05	Cone 01	Cone 5
Fire shrinkage	4.8 per cent	5.4 per cent	2.5 per cent
Color	orange	orange red	gray
Absorption	2.2 per cent		0.5 per cent

The clay was incipiently fused at cone 03, vitrified at cone 2, and viscous at cone 12. The bricklets were strong, and did not fail on burning until raised to a temperature above cone 3, the bricklet to cone 5 being warped and swelled considerably.

The high air shrinkage might be prohibitive to the employment of this clay. It could probably be used for common brick and possibly could be burned dense enough for paving brick.

At the headwaters of the Knife river and its tributaries, on the divide between these streams and the creeks leading into the Little Missouri, clays similar to those at Manning's ranch and Goodman valley are found. These are farther west than any of the other high grade clays. Running southeast for three or four miles from near the center of T. 143, R. 99, is a range of buttes. In the upper part of these the Tertiary clays are exposed, and at the base along the creeks are good seams of lignite six to seven feet thick.

A section of one of the buttes shows the following beds:

	Feet.	Inches.
Ferruginous sand	2	
Lignitic layer		1
Dark, bluish or purplish gray, somewhat sandy clay (No. 3701)	3	
Light gray to buff, sandy clay (No. 3702)	2	
Yellow and white clay (No. 3703)	2	
White, sandy clay, somewhat stained in places with iron,		

	Feet.
especially near the bottom (No. 3704-5)	12
Impure, sandy limonite	1
Dark bluish gray, carbonaceous, shaly clay (No. 3706)	4
Coarse, ferruginous sand	35
Laramie sands, impure clays and lignite	120

Samples Nos. 3702 and 3703 are much alike, and also resemble No. 3903 from Manning's ranch and No. 4004 from Goodman valley. The upper one is, however, more sandy, while the lower one contains but very little grit. The composition of these four clays are given for comparison:

	No. 3702.	No. 3703.	No. 3903.	No. 4004.
Silica	66.22	62.65	65.98	62.90
Alumina	20.51	20.76	20.68	22.68
Ferric oxide	3.49	4.98	3.98	4.98
Lime	0.23	0.26	0.29	0.32
Magnesia	0.78	0.77	0.41	0.72
Volatile matter	6.83	6.55	7.60	7.28

The physical properties are shown in the following table:

	No. 3702	No. 3703	No. 3903	No. 4004
Water required	20.9 per ct.	28.3 per ct.	22.9 per ct.	21.09 per ct.
Plasticity	good	good	good	very good
Air shrinkage	4.8 per ct.	6.0 per ct.	5.4 per ct.	5.8 per ct.
Tensile strength	95 lbs.	95 lbs.	98 lbs.	84 lbs.
Cone 05				
Fire shrinkage	1.5 per ct.	2.3 per ct.	0.5 per ct.	2.9 per ct.
Color	light pink	light red	light pink	light buff
Cone 01				
Fire shrinkage	3.2 per ct.	6.9 per ct.	6.0 per ct.	3.9 per ct.
Color	cream	yellowish brown	buff	yellow
Absorption	10.6 per ct.	6.7 per ct.		7.1 per ct.
Cone 5				
Fire shrinkage	5.0 per ct.	8.3 per ct.	8.3 per ct.	7.9 per ct.
Color	buff	dark gray	gray, spotted black	gray
Absorption	5.2 per ct.	0.7 per ct.	0.5 per ct.	0.3 per ct.
Cone 10				
Fire shrinkage	6.5 per ct.	6.7 per ct.	8.0 per ct.	6.9 per ct.
Color	gray, brown black mottled	brown black mottled	gray, spotted black	mottled brown black
Absorption	2.1 per ct.	0.6 per ct.	0.9 per ct.	0.4 per ct.
Incipient fusion	Cone 6	Cone 1	Cone 2	Cone 1
Vitrification	Cone 12	Cone 8	Cone 12	Cone 7
Viscosity	Cone 22	Cone 18	Cone 24	Cone 20

Probably the chief value of these clays would be for the manufacture of front brick, although they might also be used for dark colored stoneware.

The twelve feet of white, sandy clay (No. 3704) is more like the white, sandy, fine clay near the railroad. It is somewhat shaly or laminated, due to differences in fineness of grain. It developed only a moderate plasticity with 20.0 per cent of water. It had an air shrinkage of 3.8 per cent. and a tensile strength of 83 pounds, and dried without checking. It burned as follows:

	Cone 05	Cone 01	Cone 5	Cone 10
Fire shrinkage	0.8 per ct.	2.8 per ct.	3.9 per ct.	5.3 per ct.
Color	light pink	buff white	gray white	gray white
Absorption		15.2 per ct.	10.3 per ct.	7.2 per ct.

Incipient fusion took place ae cone 14, vitrification at cone 22 and viscosity at some temperature considerably above cone 25.

This seems to be a fair grade of fire clay and its principal use would be for the manufacture of fire brick and fire clay products by the wet mud process.

Another sample, No. 3601, from this same horizon of white, sandy clays, was tested from an outcrop about six miles southeast. The section exposed there is:

	Feet.	Inches.
Ferruginous sandstone	2	
White, sandy clay (No. 3601)	6	
Ferruginous, sandy clay	7	
Lignite		2
White, sandy clay (No. 3602)	12	
Ferruginous sand, few carbonaceous layers	50	

The sandy clay (No. 3601) is very similar to that described above (No. 3704), but the sand grains are a little coarser and the clay contains more iron. It slaked immediately in water, and required 19.4 per cent of water to temper it, but it did not become plastic. It had an air shrinkage of 1.7 per cent and a tensile strength of 40 pounds. The results of burning tests were:

	Cone 05	Cone 01	Cone 5	Cone 10
Fire shrinkage	0.0 per ct.	0.9 per ct.	1.0 per ct.	2.0 per ct.
Color	pinkish white	cream white	cream white	gray, spotted brown
Absorption	19.0 per ct.		16.6 per ct.	10.3 per ct.

The clay was incipiently fused at cone 22, giving a hard body with greenish brown spots on a light gray background. Vitrification did not occur at cone 25.

This also seems a fairly good clay for fire brick, but would have to be worked up by the soft mud process on account of its leanness.

The clays in this northern area are abundant and of varied character. There seem to be fewer high grade, white burning plastic clays than further south near the railroad. Most of the other kinds, however, are represented.

These clays are not at present available on account of the long distance from the railroad. It is reported that the construction of a railroad through this country has been considered which would probably follow the Little Missouri valley for some distance before branching off toward Williston. Such a road would undoubtedly open up some of these clays so that they would be available.

Clays South of the Northern Pacific Railroad.—High grade clays are not so plentiful south of the railroad as they are to the north. In the eastern part of the area the elevation is too low, except in the highest buttes. In the southern and western parts the clays became very calcareous, like those in the Chalk buttes near Sandcreek, which are of no value.

The white, sandy, fire clays, like the under clay (No. 111) at the Dickinson pits, can be traced to the south. It seems to underlie the entire county for about twenty miles in this direction. Along the mail road to New England these clays were exposed (in the summer of 1905) in the holes which were being dug for telephone posts. Samples collected a couple of miles apart resembled each other closely. Just east of the point where the mail road crosses Antelope creek, ten miles south of Dickinson, is a good exposure of these sandy clays. About thirty-five feet of these are shown, which grow more sandy and ferruginous near the bottom. They consist of a structureless, friable, clayey sand. The sand grains are nearly all quartz, with some mica and a few dark colored grains, coated over with a pure white kaolin. They also contain many hard, ferruginous and calcareous concretions, from small ones a half inch in diameter up to those ten and fifteen feet across. These concretions are hard and not very easily crushed, whereas the main deposit is very friable and they could therefore be easily removed. One of these calcareous concretions was in the sample subjected to chemical analysis, and the analysis of the clay there-

Fig. 1. Yellow Buttes, showing outcrops of high grade Tertiary clays.

Fig. 2. Tertiary clays exposed along Antelope creek, southwest of Dickinson.

fore probably shows more lime and iron than the average amount present. The following is the analysis:

	No. 1103.
Silica	67.60
Alumina	16.32
Ferric oxide	2.82
Lime	3.45
Magnesia	0.51
Volatile matter	7.07

The table below gives the physical properties of these clays Sample No. 1001 is from a telephone post hole six miles south of Dickinson and Nos. 1102 and 1103 are from the Antelope creek section, the former from near the top and the latter ten feet below:

	No. 1001	No. 1102	No. 1103
Water required	18.9 per cent	19.9 per cent	19.8 per cent
Plasticity	lean	lean	lean
Air shrinkage	1.4 per cent	2.0 per cent	2.1 per cent
Tensile strength	64 lbs.	60 lbs.	57 lbs.
CONE 1			
Fire shrinkage	1.0 per cent	0.0 per cent	0.0 per cent
Color	cream	cream	cream
CONE 5			
Fire shrinkege	1.3 per cent	1.5 per cent	0.0 per cent
Color	cream	light buff and brown mottled	buff and brown mottled
Absorption	13.1 per cent	15.0 per cent	16.5 per cent
CONE 10			
Fire shrinkage	2.3 per cent	2.0 per cent	2.4 per cent
Color	buff and brown mottled	buff and brown mottled	buff and brown mottled
Absorption	10.4 per cent	10.8 per cent	7.3 per cent
Incipient fusion	Cone 25+	Cone 23	Cone 22
Vitrification		Cone 25+	Cone 25

The clays fuse at a much higher temperature than they would if they were of finer grain, but they contain so much coarse silica that this acts as an infusible skeleton, which holds the clay in shape.

Their only use is as refractory material, and on account of their leanness they are best worked by the wet mud process.

Some eight miles further south, in the northern part of T. 136, R. 96, is a chain of buttes running east and west, known as the Yellow buttes. At the base of these the sandy fire clay outcrops, but is here overlain by plastic clays.

The following section occurs in these buttes:

	Feet.
Ferruginous sand	25
Light bluish gray, compact, somewhat shaly clay (No. 1201-2)	7
Blue to red, laminated and slightly sandy clay (No. 1203)	3
Dark olive gray, carbonaceous clay (No. 1204-5)	4½
White, sandy clay exposed to creek bottom (No. 1206)	10

The upper clay (No. 1201) has a very fine texture and between the teeth only slight grittiness can be detected. It slaked very easily, and with 29.8 per cent of water was tempered to a good plasticity. It had an air shrinkage of 5.0 per cent, a tensile strength of 90 pounds, and showed but little tendency to check. The results of burning were:

	Cone	Cone	Cone	Cone
Fire shrinkage	5.0 per ct.	6.0 per ct.	10.7 per ct.	11.0 per ct.
Color	cream white	cream white	light cream	gray white
Absorption			1.9 per ct.	0.5 per ct.

The bricklets did not crack on burning. The clay was incipiently fused at cone 2 and vitrified to a pure white, dense body, without warping or cracking, at cone 12, and did not become viscous until cone 22.

An analysis of the clay shows the following composition:

	Per Cent.
Silica	63.64
Alumina	24.17
Ferric oxide	0.95
Lime	0.45
Magnesia	0.98
Volatile matter	7.60

This clay is suitable for the manufacture of stoneware, white earthenware and other wares. It would, of course, have to be properly prepared and would have to be mixed with considerable flint and feldspar to keep the shrinkage within the proper limits.

Sample No. 1203 contains considerable fine sand and is laminated. It slaked very easily and became only moderately plastic with 24.6 per cent of tempering water. It shrank 3.9 per cent on drying and did not check. The tensile strength of the air dried clay was 78 pounds. The following shows the results of the burning tests:

	Cone 03	Cone 1	Cone 5	Cone 10
Fire shrinkage	2.0 per ct.	2.9 per ct.	6.0 per ct.	7.5 per ct.
Color	pink	buff	cream	gray
Absorption			8.6 per ct.	4.9 per ct.

Incipient fusion took place at cone 9, vitrification at cone 17, and viscosity at cone 25. All the bricklets burned without checking, and those burned to cone 1 or above were very strong.

This clay would hardly be as adaptable for stoneware as the overlying, No. 1202, on account of its high temperature of vitrification and its moderate plasticity. Because of its low shrinkage it would be very well suited for dry-press front brick, which could be colored artificially if desired.

The carbonaceous clay (No. 1204) is fine-grained and has but little sandy material, but it does contain small ferruginous and calcareous concretions. It slaked readily, and with 29.2 per cent of water developed a good plasticity. It had an air shrinkage of 8.3 per cent and checked a little on drying. The tensile strength was 124 pounds. When burned at a low heat it became yellow and dense without cracking, but when raised above cone 03 it started to swell and when brought to a temperature much higher warped and cracked badly. This clay is probably of no value, although a small amount of it might be mixed with the overlying sandy clay to give the latter a stronger bond at lower temperatures.

The underlying white, sandy clay is like the sandy fire clay at Dickinson, and is purer than those found just to the south of there (Nos. 1001-2). It required 20.3 per cent of water, became moderately plastic, shrank 2.7 per cent without checking, and had a tensile strength of 71 pounds. It burned as follows:

	Cone 1	Cone 5	Cone 10
Fire shrinkage	0.0 per cent	1.0 per cent	3.2 per cent
Color	light buff	light buff	white
Absorption		15.3 per cent	8.6 per cent

The clay was not even incipiently fused at cone 25.

This clay seems to be an excellent fire clay and is most valuable as a refractory material. It is best worked by the wet-mud process, although it can be worked by the dry-press.

Five to ten miles east and north of the Yellow buttes is a range of low buttes called the "Limestone Ridge." The white material capping the ridge is mostly a pure quartz sand with a clayey cement containing but little lime. About fifty feet below the top an outcrop exposes ten feet of white, sandy fire clay similar to the others which have been described.

Black Butte is a tall, stately butte rising over 300 feet above the prairie in the northeastern corner of T. 135, R. 95. About

100 feet below the top the high grade clays appear. This is the farthest point to the south and west that these clays were found, the beds at the same horizon near Sandcreek being calcareous and of low fusibility. No clays are exposed in the Tepee buttes, twelve miles southwest of Black Butte. Fire clays are reported to occur in East Rainy Butte, twenty miles west of Black Butte, by F. A. Wilder.[1] The clay referred to by him is probably the white, sandy clay below the overlying ferruginous sandstone cap. This clay is highly calcareous and would be more correctly called a calcareous sand. It would fuse at a low temperature.

The following section is exposed in Black Butte:

	Feet.	Inches.
Hard, ferruginous sandstone capping the butte, with soft sand below prevailingly ferruginous	100	
Dark gray, impure, sandy clay	1	
Light bluish gray clay (No. 2101)	3	6
Ferruginous clay	1	6
Grayish white, sandy clay (No. 2102)	3	
Dark, carbonaceous clay		8
White, sandy clay (No. 2103)	5	
Yellow, sandy clay, ferruginous	3	
White clay (No. 2104)	2	
Impure, ferruginous and carbonaceous, sandy clay	12	
Sand or unexposed	55	
Laramie sands, clays and coals	120	

The upper clay (No. 2102) is the most plastic and is fine-grained, compact and structureless. It contains a little grit and is stained somewhat with iron, but appears to be quite pure. The sandy clays below (Nos. 2102-3) are much alike, although No. 2103 is purer. The sand grains are very fine and are covered with a pure kaolin. An analysis of this clay is given below. Sample 2104 is higher in alumina (and in kaolin) than any other North Dakota clay reported. It is a compact, structureless, very fine grained clay, with practically no grittiness, and free from iron staining.

	No. 2103.	No. 2104.
Silica	76.24	60.98
Alumina	15.39	26.24
Ferric oxide	0.79	1.34
Lime	0.34	0.34
Magnesia	0.33	0.94
Soda	.....	1.22
Potash	.....	1.26
Volatile matter	5.12	7.85

[1] N. Dak. Geol. Survey, Vol. II, p. 160.

The physical tests of these four clays are given in the following:

	No. 2101	No. 2102	No. 2103	No. 2104
Slaked	easily	easily	easily	easily
Water required	24.5 per ct.	20.0 per ct.	15.9 per ct.	18.9 per ct.
Plasticity	good	moderate	good	good
Air shrinkage	6.2 per ct.	3.3 per ct.	5.5 per ct.	3.8 per ct.
Tensile strength	131 lbs.	94 lbs.	113 lbs.	110 lbs.
Dried	without cracking	without checking	checked a little	without checking
Cone 03				
Fire shrinkage	1.3 per ct.	0.0 per ct.	2.3 per ct.	0.3 per ct.
Color	cream	cream	white	white
Absorption		16.4 per ct.		
Cone 1				
Fire shrinkage	3.4 per ct.	1.2 per ct.	6.3 per ct.	0.5 per ct.
Color	yellow	pink	yellow	yellow
Absorption				14.0 per ct.
Cone 5				
Fire shrinkage	7.3 per ct.	3.9 per ct.	8.5 per ct.	2.3 per ct.
Color	gray	buff	gray white	buff and brown
Absorption	0.5 per ct.	8.7 per ct.	0.4 per ct.	12.4 per ct.
Cone 10				
Fire shrinkage	5.9 per ct.	4.3 per ct.	4.3 per ct.	2.9 per ct.
Color	gray	gray	white	buff to brown
Absorption	0.5 per ct.	3.2 per ct.	0.7 per ct.	9.3 per ct.
Incipient fusion	Cone 1	Cone 9	Cone 01	Cone 17
Vitrification	Cone 8	Cone 15	Cone 6	not at 25
Viscosity	Cone 22	Cone 24	Cone 24	

Nos. 2101 and 2103, which are plastic and burn dense at a low temperature, and which when raised above vitrifiicatoin begin to swell, might do for cheap grades of drain tile and semi-fire products. No. 2103 showed a little tendency to check, forming surface cracks on drying, but the shrinkage could probably be held up by proper mixing with a clay like No. 2102. This clay is not plastic, neither is it vitrified easily, but it might be used for pressed brick, and to mix with the more plastic clays to decrease the shrinkage of too "fat" and plastic clays.

Sample No. 2104 is in a class by itself. It is a low grade fire clay which could be worked by almost any process and molded into any desired form. Its air and fire shrinkage is low and the most difficult of shapes could be made from it. It would make excellent material for terra cotta and for other architectural pur-

poses. It could be used for glazed and colored earthenware where the color of the clay itself is obscured.

East of Black Butte but few of the higher buttes reach an elevation of 2,450 to 2,500 feet above sea level. Those that do probably all contain good clays. They were seen in White and Bull buttes, southwest of Spaulding. Heart Butte, just north of the Heart river, and south of Glen Ullin, does not show any Tertiary clays. West of Leipzig the clay outcrops in Shepards, Antelope and Clark buttes. This is probably as far east and south as they extend.

The top of these buttes is capped with white, sandy clay, which has been hardened and cemented mainly by a little calcareous cement.

At the top of Shepards Butte the following section is exposed:

	Feet.
Hard white sandstone, underlain by soft ferruginous sand..........	35
White, sandy clay, like Dickinson sandy fire clay (No. 1601)........	10
White, smooth, fine grained clay (No. 1602)......................	2
White, sandy clay, like above	10

Sample No. 1602 has probably about the same composition as the rest of the bed but is finer grained. It is a light, porous clay, with a few segregations of sandy material cemented by iron and lime. It slaked immediately and was tempered to a good plasticity with 26.0 per cent of water. It had an air shrinkage of 5.5 per cent, a tensile strength of 89 pounds, and dried without cracking. The burning tests gave the following results:

	Cone 03	Cone 1	Cone 5	Cone 10
Fire shrinkage	5.2 per ct.	5.3 per ct.	8.3 per ct.	5.3 per ct.
Color	cream	buff	gray	gray
Absorption		8.9 per ct.	0.7 per ct.	0.8 per ct.

The clay was incipiently fused at cone 2, vitrified at cone 7, and viscous at cone 18. The bricklet burned to cone 10 was swelled and badly cracked, the others were not checked or warped, but strong and dense.

Such a clay as this could probably be used for the cheaper grades of stoneware and possibly paving brick. The sandy clay above and below is probably a poor fire clay.

Along the western border of the area, as already stated, the Tertiary clays are very calcareous and also high in iron. As a general rule they are worthless, although some may be useful for cheap, red burning ware. Detailed examinations of these clays were made in the range of buttes north of Antelope creek, in T. 137, R. 97,

about eleven miles southwest of Dickinson, and in the buttes around Sandcreek.

In the former locality the section following is exhibited:

	Feet.
Sand and ferruginous sandstone	50
White, calcareous sandstone (No. 701)	5
Gray, carbonaceous, calcareous clay (No. 702-4)	25
Dark brownish, carbonaceous, calcareous, sandy clay (No. 705)	9
Grayish white calcareous clay, with but little grittiness (No. 706-7)	8
Grayish white, calcareous clay, somewhat sandy (No. 708-9)	8
White, clayey sand, contains considerable iron and lime (No. 710)	7

All of these clays, with the exception of the bottom sand, required large amounts of water, had high shrinkages, and cracked and warped badly on drying. When burned even to a gentle heat, they swelled and checked still further. These tests show that these clays are worthless.

The bottom sandy clay (No. 710) is mostly a medium grained quartz sand, containing a little mica and other dark colored minerals and a little clay bonding material. It required 23.2 per cent of water, but the tempered material was lean. It had an air shrinkage of 4.3 per cent, a tensile strength of 77 pounds, and dried without checking. The results of the burning tests are:

	Cone 05	Cone 1	Cone 5	Cone 7	Cone 12
Fire shrinkage	0.7 per ct.	0.5 per ct.	1.5 per ct.	3.4 per ct.	failed by swelling and warping
Color	red	red	red brown	greenish gray	greenish gray
Absorption		13.1 per ct.	12.8 per ct.	8.3 per ct.	
Condition	weak	rather weak	strong	strong	

Incipient fusion occurred at cone 10, vitrification at cone 12 and viscosity at cone 14.

This material might be used for common soft-mud brick, but is of rather high fusibility and does not burn strong enough at a low temperature.

Near the post office of Sandcreek are several high buttes which are generally known as the Chalk buttes, on account of their whiteness. They contain, however, little clay, and what is present is calcareous. They extend far up into the Tertiary horizons. The skull of the Oligocene ruminant, *Eporeodon major* (?), was found 250 feet from the top.

The following is a typical section of one of the buttes about two miles east of the post office:

	Feet.
Hard ferruginous sandstone, which grows softer downward and inward from the surface. The sand contains many minerals besides quartz	135
Yellowish gray, clayey sand (No. 301)	15
Hard ferruginous sandstone, growing softer downwards into an unconsolidated ferruginous sand	75
White weathering, clayey sand, quite firmly cemented by a large amount of lime (No. 302)	20
Dark brownish gray, carbonaceous and calcareous clay, contains considerable gypsum. (Nos. 303-4.) (Fossil mammal found in this bed)	40
Coarse sand and gravel, high in iron and considerable lime (No. 305)	80

Even the sand and sandy clays are of low fusibility and have no value even for common brick. Their physical properties are shown in the following table:

	Sample No. 301	Sample No. 305
Water required	25.3 per cent	26.2 per cent
Plasticity	moderate	very lean
Air shrinkage	3.2 per cent	1.0 per cent
Tensile strength	138 pounds	49 pounds
Cone 05		
Fire shrinkage	1.7 per cent	
Color	buff	
Absorption	24.1 per cent	
Cone 03		
Fire shrinkage	7.3 per cent	
Color	yellow green	
Absorption	14.2 per cent	
Cone 1		
Fire shrinkage	14.3 per cent	1.8 per cent
Color	greenish	red
Absorption		16.1 per cent
Cone 7		
Fire shrinkage		3.7 per cent
Color		gray
Absorption		2.9 per cent
Incipient fusion	Cone 02	Cone 6
Vitrification	Cone 2	Cone 8
Viscosity	Cone 3	Cone 10

The bricklets, although not cracked, were weak, and both clays are worthless.

The forty-foot stratum of dark carbonaceous clay (No. 303) is of no value on account of its high absorption, 61.8 per cent, and consequent high shrinkage, 19.0 per cent, the clay cracking to pieces on drying. It is very fine grained, but contains many calcite. gypsum and other crystals. An analysis shows it to have the following composition:

	Per Cent.
Silica	55.30
Alumina	15.21
Ferric oxide	3.65
Lime	3.94
Magnesia	4.22
Volatile matter	10.89

The following section appears in the conical shaped butte about four miles north of Sandcreek post office, the beds being lower than those in the previous section:

	Feet.	Inches.
Hard ferruginous sandstone, growing softer and finer downward, some layers being more ferruginous than others, giving the sand a banded appearance	25	
Compact, grayish white clay (Nos. 401-2)	10	
Ferruginous sand	3	
Impure lignite		3
Ferruginous sand and impure sandy limonite, also becomes carbonaceous in places	25	
Impure lignite	2	
Dark bluish gray, shaly clay, carbonaceous and calcareous, and full of gypsum crystals (No. 403)	3	6
Impure lignite	1	
Ferruginous sand	10	
Impure sandy lignite		6
Dark, carbonaceous, sandy clay	7	
Dark, carbonaceous sand and clay, with a great deal of gypsum, some well crystallized	8	
Blue, calcareous clay, with a greasy feel, containing gypsum (No. 404)	5	
Light gray, calcareous clay (No. 405)	2	
Grayish white, calcareous clay (No. 406)	7	
Impure, ferruginous, sandy clay	10	
Ferruginous sand	10	
Alternation of ferruginous, carbonaceous, and calcareous sands and sandy clays	20	
Ferruginous sand	15	
Impure clay	5	
Ferruginous sand	10	

All the clays tested from this locality had a high absorption and shrinkage and checked very badly on drying. When burned at

temperatures no higher than cone 010 they all checked and warped. These clays are therefore of no value.

A mile north of this butte the seven-foot stratum of grayish white, calcareous clay (No. 406) outcrops at the level of the prairie. It is dug here and is used for plastering the outside of the sod houses in the vicinity, being called "natural lime." It is, of course, nothing but clay. An analysis shows:

	Per Cent.
Silica	65.16
Alumina	19.16
Ferric oxide	3.32
Lime	1.04
Magnesia	1.75
Volatile matter	4.83

It also contains efflorescent salts which dry out on the clay.

This material (No. 406) developed a good plasticity with 26.1 per cent of water. It shrank 5.7 per cent on drying, did not check and had a tensile strength of 247 pounds. It burned as follows:

	Cone 05	Cone 03	Cone 1
Fire shrinkage	2.7 per cent	7.7 per cent	failed by swelling a little
Color	orange red	red brown	dark brown
Absorption	8.3 per cent	0.3 per cent	

Incipient fusion occurred at cone 4, vitrification at cone 1, and viscosity at cone 6.

The bricklets burned below cone 1 were very strong and dense. This clay might make a good drain tile and paving brick. It could also be employed for common red earthenware and for red brick. It is well adapted to the use it is put, that of plastering houses, on account of the strong tensile strength of the dried clay, and is very efficient except in wet weather.

The clays south of the railroad, although not so abundant as those north, are quite widely distributed. Directly south of Dickinson and Gladstone are clays ranging from high grade china and fire clays to those of comparatively low fusibility, suitable for stoneware. East of this area the elevation of the country falls below that of the Tertiary horizon. West and south the clays become calcareous and of low grade.

Few of these clays are at present available because of their distance from a railroad. With the development of the country, however, railroads will be built, and then such clays as are found on Black Butte will be valuable.

CHAPTER IX.

PLEISTOCENE CLAYS.

Over much the greater part of North Dakota the surface formations are of Pleistocene age. These deposits are of glacial, lake or stream origin. They are essentially superficial and do not reach any great depth, although in the Red River Valley a thickness of several hundred feet is attained, and some of the morainal hills also contain this thickness of surface material. The glacial drift is composed of a heterogeneous mixture of clay, sand, gravel and boulders. Occasionally enough clay is present for the material to be suitable for the manufacture of brick and possibly the cheaper grades of hollow ware.

Glacial Drift Clays.—The deposits of glacial drift are by far the most extensive. As a rule, however, they are unfit for use as a clay except where they have been rearranged and sorted by the agency of water. The stretches of low flat prairie are usually underlain by clay which has been washed from the surrounding elevations. The terrace and lake clays are also largely derived from the glacial drift. Thus what was originally a mixed mass of sand, gravel and clay has now, through the action of water, become somewhat sorted and stratified. It is therefore in the low, flat regions that one would look for the clays of glacial origin which are available.

Suitable clays formed in this manner occur abundantly throughout the state and in many places are or have been utilized for the manufacture of brick. Most of the clays used, although of glacial origin, have been transported and rearranged to such an extent that they are more correctly classified as lacustrine or river bottom clays. At Rolla, Jamestown and Bismarck brick has been manufactured from glacial clays which have been washed from the surrounding elevations and redeposited through the action of running water. Such clays are found widely distributed throughout the areas covered with drift. They are not very pure, being usually calcareous and sandy, while the individual deposits are also limited in extent.

The character of these clays is fairly uniform and is shown by the following descriptions. At Rolla the surface is gently rolling. The

elevations are sandy and the lower places underlain by yellow clay. A brick plant has been intermittently in operation about one-half mile south of town. It utilizes one of the clay deposits below the prairie loam. The clay in the pit is about three and a half feet thick with eighteen inches of soil above and sandy gravel below. Trouble is experienced in wet seasons with water.

The clay is of a yellow color, soft, porous and easily dug. It is tempered directly in the ring pit. It contains a good deal of sand, a few small pebbles of limestone and also mica and gypsum. A moderate plasticity is developed with 20.0 per cent of tempering water. The tensile strength was high, about 150 pounds, and it had an air shrinkage of 3.2 per cent.

Its behavior in burning was as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	2.7 per ct.	0.3 per ct.	0.5 per ct.	1.9 per ct.
Color	orange	light pink	pink	greenish
Absorption			20.7 per ct.	15.6 per ct.

The clay expanded at first due to the large percentage of sand. With the exception of the bricklet burned to cone 01 they were not very strong. After the clay starts to fuse it rapidly becomes viscous, incipient fusion occurring at cone 1, vitrification at cone 3, and viscosity at cone 4. Such a clay is of no value except for common, wet-mud brick. Even for this purpose the presence of the lime pebbles causes loss in the brick unless these are carefully screened out before manufacturing.

Over ten years ago a brick plant was in operation at Jamestown. The pits were located on the prairie, which is about 100 feet above the town, and near the railroad track about two miles east of the station. The clay used was the glacial subsoil, which is quite sandy, but is said to grow more clayey downwards. The old pits are now nearly overgrown but showed about eight inches of black loam and four feet of yellow sandy clay.

The clay is soft, structureless, unconsolidated and can be tempered directly. It is mostly a fine sand with little clay substance. It contains a few small lime pebbles but except for these is quite free from lime. Iron, carbon and mica are present in considerable quantities. With 22.4 per cent of water it develops only a fair plasticity. It had a tensile strength of 166 pounds. The air shrinkage was 3.0 per cent.

The burning tests show the following results:

Clay pits at Bismarck, showing glacial till overlying Laramie sands.

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.8 per ct.	0.8 per ct.	0.5 per ct.	1.5 per ct.
Color	orange red	light red	red	red brown
Absorption	17.1 per ct.	17.5 per ct.	17.9 per ct.	13.4 per ct

The bricklet burned to cone 01 was strong, but the others were not. Incipient fusion occurred at cone 2, vitrification at cone 7, and viscosity at cone 9. This clay is probably not plastic enough for the stiff mud process but makes an excellent material for soft mud brick. It can be dried quickly without checking, and can be burned hard without danger of over-burning, which is possible with most glacial clays which are high in lime. The brick which were made here over ten years ago have stood the test of weathering very well although they are now soft, but the brick could have been burned much harder than they were.

The brick plant at Bismarck is located about a mile west of town, near the railroad track. The clay used is a glacial till which decreases in thickness as the face of the pit is pushed back further into the hill. The clay seems therefore to have been washed from the hill into the valley, attaining a maximum thickness of ten feet. Below the drift occurs the Laramie sands.

The clay is soft, and is tempered directly in soak pits. It is a dark yellow, porous clay, composed mostly of fine sand, with a little clay substance, contains a few pebbles and is high in lime. It required 26.1 per cent of tempering water for its maximum plasticity, which was moderate. The air shrinkage was 6.1 per cent, but it dried without checking. The burning tests were as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.4 per ct.	1.1 per ct.	3.0 per ct.	failed
Color	light red	red	red	dark brown
Absorption	22.0 per ct.	19.9 per ct.	14.6 per ct.	19 per ct.

It was incipiently fused at cone 02, vitrified at cone 1, and became viscous at cone 3. The bricklets were strong. Burned to about cone 03 a good, strong, fairly hard brick can be made by the soft mud process.

These show the character of the material that one may expect to find in the glacial drift. Clay fit for the production of a low grade, soft-mud brick can doubtless be found in many localities not specifically mentioned.

Lake Bottom Clays.—The valleys of the northward flowing rivers were dammed up by the edge of the retreating ice sheet toward the

close of the glacial period, and great lakes were formed. In North Dakota there were three such lakes, Lake Agassiz, Lake Souris and Lake Dakota. Besides these larger lakes many smaller ones were formed, which like the larger have since been drained off. Into these clay was carried by the inflowing streams and deposited on the bottom. The sediments thus laid down are sandy and calcareous and were derived mainly from the Pierre and other Cretaceous shales, and from the glacial drift. These stratified lake clays reach a thickness of from 50 to 100 feet in the Red River Valley.

Only the yellow subsoil underlying the surface loam has been employed as yet for the manufacture of brick. This consists of a sandy, calcareous clay which is very uniform in its character and properties throughout the valley. It is overlain by a foot or two of black surface loam, from eight to ten inches of which are stripped off in working Directly underlying the yellow clay is a mottled yellow and blue clay about three feet thick, known as "joint clay." It is harder than the overlying material and grades downward into a blue clay of indefinite thickness. The typical yellow clay which is dug for brick is about three and one-half feet thick at Drayton and thins out toward the south, so that the pits at Fargo and Abercrombie are very shallow, only two feet to eighteen inches being used. At Grand Forks about a foot of the "joint clay" is mixed in with the yellow.

The clay is rather sandy, is light and porous, containing roots and other carbonaceous material. It is colored yellow by the oxidized iron, is highly calcareous and carries small lime pebbles and mica. It only develops a moderate plasticity, and fuses at a low temperature (about 2,200 degrees F.), with a very small range of from 100 degrees to 200 degrees F, between incipient fusion and viscosity. The bricks when underburned are pink, but properly burned at 2,000 degrees F. are cream colored.

At Drayton there is exposed in the pits about three and a half feet of yellow clay, overlain by eight to ten inches of black loam, and underlain by the joint clay grading into the blue clay. The yellow clay is sandy and is high in carbon, iron and lime. It is soft enough to go directly from the pit to the pug mill. It required 26.3 per cent of tempering water and developed a moderate plasticity. It had an air shrinkage of 4.8 per cent and the tensile strength of the air dried clay was 173 pounds. The burning tests were as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	1.0 per ct.	1.4 per ct.	1.0 per ct.	1.9 per ct.
Color	light cream	light cream	cream	light greenish
Absorption	29.7 per ct.	30.5 per ct.	30.7 per ct.	24.2 per ct.

The bricklets were strong and those burned to cone 01 nearly steel hard. Incipient fusion occurred at cone 2, vitrification at cone 4, and viscosity at cone 5.

At Grand Forks the yellow clay is about three feet thick. It is overlain by a foot or more of black loam, ten inches of which is stripped off and the rest mixed with the clay. About a foot of the underlying "joint clay" is also dug and mixed in with the rest. The sample from the Dinnie yard showed a texture similar to that from Drayton, but contained a little more sandy material. It required 25.1 per cent of tempering water and developed only a fair plasticity. The air shrinkage was 2.7 per cent and the tensile strength 127 pounds. The burning tests gave results as below:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.5 per ct.	1.0 per ct.	0.1 per ct.	2.0 per ct.
Color	orange	pink	cream	cream to greenish
Absorption	31.4 per ct.	33.1 per ct.	22.5 per ct.	17.9 per ct.

The bricklets, except the one burned to cone 01, were not very strong. The clay was incipiently fused at cone 1, became rapidly vitrified at cone 3, and viscous at cone 4.

The following is an analysis of the same clay from the Alsip yard in the northwestern part of the city limits, formerly worked:[1]

Silica	51.27
Alumina	9.33
Ferric oxide	3.52
Lime	11.15
Magnesia	2.31
Soda	2.08
Potash	0.50

The yellow clay at Fargo and Abercrombie, although thinner, has very nearly the same properties. The action of the clay in burning for brick in the different localities is very similar. It is doubtful whether it is of any value except for cream-colored, soft-mud common brick, although a good quality of these can be manufactured.

[1] E. J. Babcock; N. Dak, Geol. Survey, Vol. I, p. 40.

But little work has been done on the underlying "joint" and blue clays. A sample of the former from the bottom of the pit in the Dinnie yard at Grand Forks, and therefore about five feet from the surface, was tested and gave the following results. It contains more clay substance than that yellow clay, although considerable fine sand is still present. The iron is oxidized to a yellow color in streaks along the joints. Carbon and lime are also present in rather large quantities. It takes 29.6 per cent of tempering water for the best plasticity, which is good. The tensile strength is 255 pounds, and the air shrinkage 5.3 per cent. In burning its behavior was as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.0 per ct.	0.3 per ct.	0.0 per ct.	failed by cracking
Color	orange pink	pink	pink	green
Absorption	30.3 per ct.	30.9 per ct.	30.3 per ct.	10.1 per ct.

Incipient fusion occurred at cone 02, vitrification at cone 1, and viscosity at cone 2. The bricklets were all strong. This clay alone would probably be valueless, but because of its good plasticity and high binding power, it could be mixed with a sand or a sandy clay and worked by the stiff-mud process for the manufacture of common brick and possibly paving brick. Several tests have been made for the use of this clay as a paving material. In some cases, with a correct mixture, fair results were obtained.

At Hall's Spur, about three miles north of Omemee, there is located a brick plant which uses the clay laid down in the old glacial Lake Souris. The material is similar to the Lake Agassiz clay. In the pit is exposed four feet of yellow clay subsoil, overlain by about a foot of black loam. The clay is high in fine sand and low in clay substance. The sand contains much mica, and is probably calcareous. The clay is of course soft and does not have to be prepared except in soak pits or in a pug mill. It required 25.1 per cent of water to develop its best plasticity, which was but lean, although the tensile strength was 161 pounds. The air shrinkage was only 0.5 per cent. The burning tests gave the following results:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	3.0 per ct.	0.8 per ct.	3.0 per ct.	4.3 per ct.
Color	light red	light red	gray green	green
Absorption	30.9 per ct.	24.1 per ct.	18.1 per ct.	17. per ct.

The bricklets burned to 010 and 05 were very weak, crumbling to pieces easily. The one burned to 03 was not very strong, but burned to 01 it became strong, though warped a little. Incipient fusion occurred at cone 1, vitrification at cone 3 and viscosity at cone 4.

Similar clays are found underlying the area covered by this old lake, which includes the greater part of Bottineau and McHenry, and bordering portions of Rolette, Pierce and Ward counties. Some of the clays are probably more plastic, but they will probably not be of any value except for the manufacture of common soft-mud brick.

River Bottom Clays.—Along the principal streams alluvial flood plains and terraces are found. These are well developed along the Missouri, especially where its various tributaries enter. The Mouse river flows through a broad, flat valley, the flood plain having been formed when the river was much larger than at present. This is also true of the James and Sheyenne rivers. The Red river flows in a shallow, narrow channel, and its flood plain is heavily wooded, as are the flood plains of its tributaries. Still, the alluvial clay from the flood plain of the Goose river at Hillsboro is mined for brick manufacture. The bottoms of the western rivers, the Knife, Heart and Cannon Ball, are sandy. These river bottom clays are used for brick at Williston, Minot, Hillsboro and Mandan.

At Williston the Muddy river and Stony creek flow into the Missouri and form a very broad flat of river laid alluvium, with two terraces. At the north end of the town the alluvium is dug and used for making brick. The top two or three feet of yellow sandy clay is mixed with a lighter clay below, which, when used alone, cracks on burning because of the lime pebbles present. The clay is quite lean and has little binding power, so that the bricks are rather soft, unless burned nearly to vitrification, which is difficult to do without injuring part of the kiln.

The underlying buff clay is very sandy, with a little fine clayey material. It is ferruginous and calcareous, required a rather large amount of water (30 per cent) to give the clay any plasticity, and at the best was lean. The air shrinkage was only 0.4 per cent and the air dried clay was very weak. Its behavior in burning was as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.3 per ct.	0.7 per ct.	0.8 per ct.	0.8 per ct.
Color	light pink	gray buff	gray	light green
Absorption		30.1 per ct.	20.9 per ct.	21.8 per ct.

The bricklets were rather weak, except the one burned to cone 01. This was strong but cracked badly. Incipient fusion occurred at cone 2, vitrification at cone 4 and viscosity at cone 5.

The top clay is more ferruginous, contains less lime and burns to a good red color. This clay was used by Mr. Metzgar, several years ago, for making brick, being dug on the flat next to the Missouri River. A sample from one of the terraces where the deposit is about six feet thick was quite plastic and burned to a strong red brick without cracking.

About a mile southeast of Minot on the flat of the Mouse river there is a brick plant. This is equipped for the production of stiff-mud and soft-mud bricks, although as yet only soft-mud brick have been produced. The upper clay, which has been used for the soft mud brick, is a lean, sandy loam, ferruginous and calcareous, with little limestone pebbles in it. It burns to a soft, red brick. There is about six feet of this clay. Below it in the western part of the pit is a yellow clay of moderate plasticity, which will be used with the stiff mud machine. At the eastern end of the pit, about six feet of a lean, yellow, sandy clay directly underlies the clay loam, so that the more plastic clay is probably of limited extent.

There is another plant using river alluvial clay at Hillsboro, located on the flat of the Goose river. About six to ten feet of clay is worked. It is soft and sandy, with many very small limestone pebbles and carbonaceous particles in it, and with but little clay substance. An unburned brick was tested with the following results. It required 26.5 per cent of tempering water for its maximum plasticity, which was good. It had a tensile strength of 189 pounds, and an air shrinkage of 5.3 per cent. In burning the results were:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.0 per ct,	0.3 per ct.	0.3 per ct.	4.0 per ct.
Color	orange red	orange red	light red	brown and greenish
Absorption	24.7 per ct.	24.4 per ct.	23.5 per ct.	14.1 per ct.

The bricklets were strong and were not cracked, and the one burned to cone 01 was steel hard. Incipient fusion occurred at cone 1, vitrification at cone 4, and viscosity at cone 6. This makes an

Clay pits of Hillsboro Brick Company.

excellent material for common brick and could probably be used by the stiff-mud process.

At Mandan, on the flat of the Heart river about a mile west of the town, is situated a small brick plant. In the pits are exposed two feet of overlying material, though to be filled in artificially, and consisting of Laramie clay, sand, shale, limestone and sandstone, and six feet of a yellow, sandy alluvial clay, becoming gradually more sandy downwards. The stones are hand picked from the overlying material, and the rest allowed to become mixed with the alluvium, giving it added plasticity.

An unburned brick was tested. It required 28.9 per cent of tempering water and the resulting plasticity was good. The air shrinkage was high, 7.9 per cent, but the clay dried without cracking, possibly due to its high tensile strength, 263 pounds. The results of the burning tests were as follows:

	Cone 010	Cone 05	Cone 03	Cone 01
Fire shrinkage	0.4 per ct.	0.6 per ct.	3.0 per ct.	failed
Color	light red	light red	red	dark brown
Absorption	19.9 per ct.	19.4 per ct.	16.3 per ct.	3.6 per ct.

The bricklets were strong and not cracked, except that burned to cone 01, which was bloated somewhat. The clay was incipiently fused at cone 02, vitrified at cone 2, and became viscous at cone 4.

As a rule, one may say of the alluvial clays that they are sandy and lean, and also that they are calcareous and ferruginous.

CHEMICAL ANALYSES OF NORTH DAKOTA CLAYS.

Laboratory Number	LOCATION.	Silica (Si O_2)	Alumina (Al $_2$ O_3)	Ferric Oxide (Fe$_2$ O_3)	Lime (Ca O)	Magnesia [1] A (Mg O)	Soda (Na$_2$O)	Potash (K$_2$O)	Loss on Ignition	Total.
	TERTIARY CLAYS									
105	Dickinson Brick Co.'s clay bank......	66.55	23.22	1.16	0.29	0.61	......	.....	7.09	98.92
111		73.20	18.56	0.30	0.29	0.52	0.38	0.36	5.93	99.74
303	Chalk Buttes east of Sand Creek P. O...	55.30	15.21	5.65	3.94	4.22	......	......	10.89	93.21
408	Chalk Buttes, north of Sand Creek P.O.,	65.16	19.16	3.32	1.04	1.75	......	......	4.83	95.26
803	Buttes, 9 miles southwest of Dickinson.	66.48	19.55	2.49	0,84	1.16	......	...	7.45	97.97
1103	Antelope Creek, 10 miles south of Dickinson..................................	67.60	16.32	2.82	3.45	0.51	......	......	7.07	97.77
1201	Yellow Butte................................	63.64	24.17	0.95	0.45	0.98	......	......	7.60	97.79
2103	Black Butte..........................	76.24	15.99	0.79	0.34	0.33	....	......	5.12	98.21
2104		60.98	26.24	1.34	0.34	0.94	1.22	1.26	7.85	100.17
2401	Buttes between Gladstone and Dick-	75.27	17.29	0.83	0.46	0.18	Trace	0.32	5.75	100.10
2402	inson, north of railroad..............	65.70	22.07	1.33	0.23	0.36	......	......	6.90	96.59
2403		65.03	23.16	1.00	0.29	0.44	......	......	7.21	97.13
2607	White Buttes, 9 miles northeast of	70.27	20.81	0.33	0.23	0.26	......	......	6.38	98.28
2608	Dickinson	75.65	17.85	0.49	0.23	0.18	Trace	0.68	5.31	100.59
2905	Hebron Brick Co.'s clay bank...........	73.90	16.49	1.25	0.29	0.46	0.22	1.20	5.52	99.33
3304	Buttes 1¼ miles north of Taylor........	65.46	20.97	1.83	0.23	1.14	0.72	1.36	6.79	98.52
3502	Buttes, 2 miles north of Gladstone......	65.64	22.74	1.66	0.29	0.61	1.76	1.46	6.15	100.31
3702	Divide, between Knife and Little	66.22	20.51	3.49	0.23	0.78	......	......	6.83	98.06
3703	Missouri rivers.......................	62.65	20.76	4.98	0.26	0.77	......	......	6.55	95.97
3903	Breaks of Little Missouri at Man-	65.98	20.68	3.82	0.29	0.41	......	......	7.60	98.78
3904	ning's ranch..........................	53.32	23.76	9.30	0.25	1.26	0.10	2.10	8.50	98.59
3906		63.19	23.35	1.49	0.29	0.98	......	......	7.82	97.12
4004	Goodman Valley......................	62.90	22.68	4.98	0.32	0.72	......	......	7.46	99.06
4008		63.90	25.79	1.49	0.25	0.25	......	......	7.28	98.96
	BENTON AND NIOBRARA.									
5503	Valley City..............................	29.27	10.74	3.82	26.98	1.53	.....	......	23.59	95.63
5901	Mayo Brick Co.'s clay bank...........	69.90	10.66	2.32	1.04	2.10	......	......	6.09	92.11
	LARAMIE CLAYS									
1501	Mott	57.94	17.46	4.58	4.14	3.84	......	......	7.67	95.65
2201	Coal mine north of Black Butte.........	57.12	19.24	4.98	2.28	3.00	......	......	8.19	94.79
3201	Coal mine at Richardton...............	61.67	17.41	3.65	2.32	3.71	......	......	6.07	94.83
3911	Manning's ranch on Little Missouri....	56.42	16.93	7.47	2.61	3.16	......	......	7.58	94.17

(1) The first one or two numbers of the laboratory number refer to the locality numbers on the map. The last two indicate the sample number.

PART IV

THE USES AND VALUE OF NORTH DAKOTA CLAYS

BY

E. J. BABCOCK

THE USES AND VALUE OF NORTH DAKOTA CLAYS.

E. J. BABCOCK.

CONTENTS

CHAPTER X.

THE USES AND VALUE OF NORTH DAKOTA CLAYS.

INTRODUCTION.

The uses of clays are dependent upon the intimate blending and resultant effect of many chemical and physical properties. It is therefore impossible to arrive at a reliable estimate of the value of a clay for a given purpose without having made a very careful investigation of these various chemical and physical properties.

To most people, clay is nothing but clay, the delicate variations in character and composition, which really determine the adaptation and value of a clay, being too commonly overlooked. This is especially true with reference to the chemical composition of a clay. There are too many instances in the clay industry where development has been undertaken and failure resulted because the character of the clay was estimated wholly upon its physical properties. No clay industry should be established without first having a knowledge of the average chemical composition of the deposit derived from a number of reliable analyses. This is particularly true of all clays to be used for the production of a higher grade than common brick, and it should also be done even for common brick.

The conclusions arrived at with reference to the adaptation and value of clays mentioned in this chapter are based upon a large amount of work which has been done in the laboratories of the College of Mining Engineering, under the direction of the writer of this chapter, and also from many years practical experience by the writer with the clays of this and other states.[1]

No one clay, however good, is fit for all uses, and usually the range of adaptation is rather limited. The greatest care should be taken to determine what this range is for a given clay before embarking upon the development of an industry. Not infrequently, persistent efforts are made to secure from a clay products for which it is utterly unfitted, while in many cases the same clay may be

[1] In order to provide for thorough and practical testing, an experimental clay-testing plant is being developed in connection with the College of Mining Engineering.

admirably adapted for the production of quite different but equally valuable materials.

Every clay must be adapted to the peculiar requirements and methods of treatment necessary for the manufacture of the product desired. It is far better to expend some time and money in a thorough preliminary testing of a clay to determine its adaptation than to learn that it is unfitted for a certain use after the expenditure of large sums of money in the equipment of a plant.

The value of a clay for a given purpose often depends upon some apparently small point in connection with its composition or physical character. For example, the color may be wrong, the fusion too low, shrinkage in drying or burning too great, or the presence of some unnoticed impurity, any one of which may be sufficient to render the clay unfit for the purpose desired.

The basis of all clay is essentially a silicate of aluminum but most clays contain, besides the aluminum silicate, a variety of other substances such as iron, lime, magnesia, potassium, and sodium. and other compounds which greatly modify the character of the original clay body. All varieties of clay originate from the disintegration of feldspathic rock. The parent rock, subjected to the action of weather and water, and finally to chemical agencies, is broken, ground and separated into sand and clay. The harder pure quartz of the rock remains in coarser grains as sand and the softer feldspar, by the further wearing and chemical action, is reduced to an impalpable state and finally deposited as a bed of clay. For example, a rock containing much iron or alkaline matter, would be likely to form a clay containing a considerable proportion of these constituents, while a rock quite free from such ingredients would, unless contaminated by foreign matter, produce a comparatively pure clay. Impurities are often added to clays during the time of transportation and deposition. After deposition the character of the clay is often if not always subject to a modification corresponding to the make-up of the superimposed material. Water percolating through an overlying deposit is almost sure to find some soluble contstituent such as lime, iron, or alkalies, which it carries with it till it reaches the underlying clay, where, on account of the compact nature of the deposit, the water passes very slowly and so allows a portion of the elements which it holds in solution to be deposited in the clay. Thus we have another cause of the varieties of clay.

In some cases water percolating through clay does not add impurities, but probably tends to purify it. This may be the case when coal, especially pure lignite, overlies the clay. Under such conditions the lignite probably acts much like charcoal, as an absorbent filter, to remove matter in solution in the water. The water thus being left quite free from the lime, iron, alkalies, etc., instead of contaminating the under clay might, whatever works its way through, serve as a wash to carry off some of the soluble matter of the clay. Whatever the cause, it is a fact that the purest clays not uncommonly underlie coal seams.

Variations in the character of the rock from which clay is derived, and variations to which the clay is subject during and after deposition, are sure to produce clays of decidedly different character. So it is that we have clays of all grades ranging from those so impure and mixed with sand and pebbles as to be unfit for the coarsest uses, to those so pure that from them can be made the most beautiful and delicate potter's wares.

On account of the variation in quality and character of wares of a given class and on account of the blending in many cases of one kind of ware with another, it is impossible to prescribe within clearly defined limits the character of clays for certain uses. For the purpose of this report, we shall consider the clays briefly under the following classes: *Architectural materials,* such as brick, terra cotta, paving brick, etc.; *Refractory materials,* such as fire bricks, stove lining, etc.; *Semi-porous ware,* such as drain tile, flower pots, etc.; *Stoneware* (semi-vitrified or partially glazed), such as sewer pipes, jars, jugs, etc.; *Earthenware* (with white or yellow body, taking good glaze), such as table ware, sanitary ware, ornamental tiles, and art pottery.

ARCHITECTURAL MATERIALS.

Among the many important uses to which the coarser clays are put is the manufacture of brick and architectural material. Clay fit for this purpose is quite common especially for the inferior grades. The characteristics of clay suited for such production are not necessarily very closely defined. This fact is readily recognized when we consider the great variety in kind and quality of brick and other structural materials. Among the many different kinds of brick and architectural products the following typical classes may be mentioned: Common brick, plastic ribbon made brick, pressed

brick, ornamental brick, terra cotta and paving brick. Of each of these general classes there are a great many varieties.

Common brick is used for rougher construction work and for ordinary building purposes. Plastic brick, made by the auger ribbon machine, usually occupies a position midway between common and pressed brick and is oftentimes used as a substitute for pressed brick. It sells at a considerably lower price and is much more cheaply made. A large number of the North Dakota clays are especially well adapted to the use of the auger ribbon machine. For extra fine products these bricks are sometimes repressed before burning. Such brick and ordinary pressed brick give much sharper edges and smoother faces, and should be uniform in color. They are used where a better finish than that obtainable from common brick is desired.

Ornamental brick or terra cotta is used for trimming and decorative purposes. It is manufactured in a great variety of ways and is frequently artificially colored or even glazed. It is hard to manufacture, requiring much skill and high grade material. It is therefore expensive.

Paving brick is used as a substitute for stone and other material in the construction of city streets. This material is burned hard and partially vitrified. It finds considerable use also for building purposes. It is most commonly made by the plastic process on the ribbon or auger machine.

It will thus be seen that very widely different materials must be used to produce such different products. However, in general it may be said that a good clay for architectural material must be free from pebbles and from too great a proportion of sand, lime and alkalies. It must also not shrink or crack readily in drying or burning and it must produce a good hard, strong body. The color may vary widely, and in fact there is a great difference in people's choice as to the color of building materials.

Red is the most common color and is due to a varying percentage of iron present in the clay. In North Dakota, however, our common brick clays and ever our higher grade pressed brick clays are, many of them, so low in iron that they burn to a white, creamy or light red tint.

For common brick there is not likely to be any difficulty in finding clay sufficiently free from an excessive amount of lime, alkalies and iron, though a combination of these elements in too large proportion oftentimes occurs. An excess of lime may have the ten-

dency to give a brittle product at a low heat, or a fused, discolored product at a high heat. Limestone in small fragments in clay is sure to produce very unsatisfactory ware as the limestone lumps are converted into free lime during burning and when the bricks are exposed to moisture this lime unites with water and swells, and frequently cracks the brick. Some clays, however, which contain a considerable amount of lime and alkalies, if present in a finely divided condition and if properly handled, produce an excellent material where resistance and abrasive qualities are sought rather than delicacy of tint or power to resist high heat. In all cases the clay must be sufficiently plastic to work well and must be tempered, if need be, with burned clay or sand to prevent too great shrinkage. Care, must, however, be taken to avoid the tendency to overload the clay with either sand or grog. This is not infrequently done with plastic clay in order to render it more easily handled. Cavities and fusion spots are often produced when the material used has not been screened or reduced to a fine condition, and contains lime or iron sulphide nodules or fragments of organic matter. This difficulty can be largely overcome by carefully screening or grinding and mixing.

The color is dependent not only upon the iron present but also upon the degree of heat and the presence of sufficient oxygen during the burning. A small poroportion of iron ordinarily will produce a light color but, in some cases, a strong heat may produce a lighter color than would be the case with much iron and a low heat.

It should be remembered that the greater portion of the brick and other material of this class is not of the highest grade. Where a superior quality can be made, especially at only a small additional expense, there is an enormous advantage to the manufacturer on account of the higher prices obtained. Some of the best grades of brick, terra cotta, and other constructional material can be made from the more impure potter's clay found in the southwestern part of the state. The general physical character of a few of the lower grade brick clays of North Dakota may be seen by the following table of physical tests:

Location	Formation	Water required Per Cent	Air shrinkage Per Cent	Tensile strength lbs. per sq. in.
Grand Forks	Pleistocene Lacustrine	25.1	2.7	127
Hillsboro	Alluvial	26.5	5.3	189
Bismarck	Glacial	26.1	6.6	
Kenmare	Laramie	20.6	4.9	118

Location	Formation	Plasticity		Fire shrinkage Per Cent	Absorption Per Cent	Color
Grand Forks	Pleistocene Lacustrine	fair	Cone 05	1.0	33.1	pink
			Cone 01	2.0		cream
Hillsboro	Alluvial	good	Cone 05	0.3	24.4	orange red
			Cone 01	4.0	44.1	brown
Bismarck	Glacial	moderate	Cone 05	1.1	19 9	red
			Cone 01		cracked and warped	
Kenmare	Laramie	good	Cone 05	0.9	23.1	pink
			Cone 01	0.3	22.0	buff

The chemical composition of brick clays varies greatly. They are usually rather high in silica, lime, magnesia and iron, and ordinarily fuse at a rather low temperature. The following table is suggested by Ries as indicating roughly the maximum, minimum and average percentage composition of common brick clays:[1]

	Range. Per Cent.	Average Per Cent.
Silica	34.35 —90.87	49.27
Alumina	22.14 —44.00	22.774
Lime	0.024—15.38	1.513
Iron oxide	0.126—33.12	5.311
Magnesia	0.02 — 7.29	1.052
Alkalies	0.17 —15.32	2.768
Water	0.05 —13.60	5.749
Moisture	0.17 — 9.64	2.502

Clays used for the manufacture of pressed brick are of a somewhat higher grade than those used for common brick, but the general principles which have already been mentioned apply to pressed brick and ornamental products. Greater care, however, needs to be taken in the selection of the clay and in the preparation of the material before it goes to the press. If the clay is too fine-grained and sticky it is apt to bother in the molds and give heavy fire shrinkage. This can be partially overcome by adding grog. Too lean or sandy or overgrogged clays usually produce soft, brittle pressed brick. Such bricks suffer materially in handling and are not good because too porous. Soft, porous pressed brick is not desirable for ordinary building purposes.

Some manufacturers have a tendency to oversand or overgrog the material. One not infrequently meets with cases where unusually high grade clay has been nearly ruined for pressed brick by being overgrogged. Pressed brick usually burns somewhat harder than mud brick or auger-made brick, and unless the temperature is high enough to produce bonding the brick are liable to be soft and crumbly. Light-colored pressed brick are usually produced

[1] New Jersey Geol. Survey: Vol. VI, p. 219.

from purer clays, containing small percentages of iron, while red and brown colors are produced from clays high in iron, or sometimes from a mixture of artificial coloring matters with the raw clay. Mottled effects are produced by mixing small fragments of different clays or foreign substances with the ground clay before it is molded.

The following table of physical tests will give an idea of some of the characteristics of a few of the pressed brick clays of North Dakota:

Location	Formation	Water required Per Cent	Air shrinkage Per Cent	Tensile strength lbs. per sq. in.
Dickinson	Tertiary	27.7	3.0	160
Hebron	Tertiary	20.6	3.8	122
Wilton	Laramie	21.6	5.3	227
Mayo	Benton	46.3	5.7	108

Location	Formation	Plasticity		Fire shrinkage Per Cent	Absorption Per Cent	Color
Dickinson	Tertiary	very good	Cone 1	3.6		light buff
			Cone 5	5.8	8.0	light buff
			Cone 10	7.3	2.6	gray white
Hebron	Tertiary	good	Cone 01	1.0		light buff
			Cone 5	2.9	10.6	light buff
			Cone 10	5.8	1.8	light gray
Wilton	Laramie	very good	Cone 05	0.0	16.6	orange red
			Cone 01	2.5	5.9	green
Mayo	Benton	moderate	Cone 05	4.3	21.8	orange red
			Cone 01	7.3	15.8	red brown
			Cone 5	9.3	8.5	dark brown

The geological horizon of clays suited to different uses varies widely from the earliest to the latest formations. Especially is this true with reference to the clays used for the manufacture of common brick and other architectural material. Coarse clays suited for these purposes are frequently found in drift-covered districts where the underlying deposits are free from sand, pebbles and excess of limestone. This is how some of the brick clay in northern Minnesota and Dakota occurs. This material is also often found as lake and river deposits which have been formed by the disintegration of surrounding or distant gneissic or feldspathic rock or from shale. It can readily be seen that clays of such origin are not likely to be of high grade on account of contamination by objectionable foreign matter.

A better grade of coarse clay is often found with the clays of the Cretaceous and Tertiary formations. From this some excellent brick, terra cotta and drain pipes may be made. Some of the coarse clays of central and western North Dakota are of this kind and will doubtless prove their worth. It would naturally be inferred that

material so different in its origin varies also in its composition and characteristics and so produces articles of widely different values. The essentials in every case are a sufficient proportion of true clay basis or kaolin element to produce a plastic, workable body, free from pebbles and from an excess of sand and fusible material. Variety in the color of brick generally results from varying proportions of iron and the intensity of the heat to which the brick is exposed. Hard, dense, semi-vitreous brick result usually from clay with much fluxing material, such as the alkalies and iron.

North Dakota is remarkably well supplied with good brick clays. They are so well known that but little need here be said in regard to them. Fair brick clays may, I think, be found in most parts of the state. Over a considerable district in the eastern part, these clays appear in two distinct beds, i. e., the upper, usually yellow clay, immediately under the soil, and the deeper blue clay. In most if not all cases in this district, brick is made from the yellow clay. Still it is quite probable that a judicious and thorough mixing of the blue and yellow clays would often produce a better article.

In the Red River Valley the yellow clay immediately under the soil affords material for a first-class cream brick. It is the clay used extensively in Grand Forks.

In the north central portion of the state, there are near the surface shale deposits of considerable thickness which would doubtless in many cases make excellent brick.

In the western portion of the state there is a variety of clays. In many localities the coal clays may produce fine brick and terra cotta.

It is probable that the shales about Park River, Milton, Langdon, etc., along the Great Northern railroad to the north, will produce good brick if properly utilized. They would be likely to produce a firm, siliceous red brick.

At Kenmare on the Soo railway and near Minot and Williston on the main line of the Great Northern railroad there are clays that will make a fine, dense brick, in color from light cream to red.

Near Bismarck there are two or three layers of clay fit for excellent red brick. On the bank of the Missouri river, north of the Northern Pacific railroad bridge, near Bismarck, two layers appear well suited to this use, as well as to the production of drain and sewer pipes. One of these clays is a rather sandy gray clay; under

this is a dark carbonaceous clay, somewhat plastic and apparently adapted for making strong, dense drain pipe, roofing tile, brick, etc.

About Dickinson the great variety of fine clays afford abundant material for the finest kind of brick and terra cotta of different kinds. The best of these clays run into fine fire clay and earthenware clay, and seem too valuable to be used for common brick. They will be further considered under the head of fire and earthenware clay.

In many places in Stark, Hettinger, Morton and Mercer counties there are deposits of good clay for common brick and even pressed brick. Most of the clays mentioned for pressed brick could be used for common brick.

PRESSED BRICK CLAYS.

Clays adapted to the manufacture of pressed brick are much more exacting in their character both as to chemical and physical properties, and therefore much less abundant than common brick clays. However, the best of common brick clays frequently blend into pressed brick clays. There is an infinite number of kinds and qualities of pressed brick; still in a general way the same principles which were brought out in the discussion of the requirements of a common brick clay and the effects of impurities will apply, only with much more force, to clays to be used for pressed or front brick.

The basis of a good pressed brick clay usually approaches much more nearly to a kaolin than does common brick clay, and with the exception of iron, which occurs in widely different quantities, the best front brick clays are usually fairly pure.

As a high crushing strength is usually demanded of pressed brick, it is not desirable to have an undue amount of free silica or sand in the clay, since this always tends to materially lessen the bonding unless the brick is burned at a high temperature.

Smooth surfaces and sharp edges are very important in face brick. In order to obtain these the clay must be fine and reasonably plastic. The more plastic clays usually develop finer surfaces and harder brick.

The tint varies from almost pure white in the higher grade clays to a deep red, the shade being largely due to the amount of iron present. Most of our North Dakota clays are rather low in iron and produce light colored brick. Some of the clays are high in iron, as will be seen from the analyses, and they are capable of giving excellent shades of red. Lime should be low, as it tends

not only to make the brick soft but, when burned at a high temperature, it unites with the iron and reduces its color effect, while if burned at a low temperature it is likely to leach out by the action of water and whiten or stain the surface of the brick. The same holds true with reference to magnesia. Soluble salts such as sulphate of iron, magnesium sulphate or the alkalies should not be present, for they not only reduce the quality of the brick but also discolor it.

There are a great variety of colors required in face brick. With a clay burning to white or cream color for the foundation and with a clay rich in iron to mix, a great variety of simple shades can be produced. By grinding one of these clays fine and the other coarse and mixing, a mottled brick will be produced, the color effect of which may be modified by varying the proportions of each clay. Depth of color can be added to clays containing more or less iron by the use of a small amount of manganese. Other coloring matters are occasionally used.

Pressed brick demands great attention in all stages of manufacture, but especially so in proportioning the grog, in burning and in sorting. There is a tendency among some manufacturers to use too much grog, which produces a porous and brittle brick unless the grog is easily fluxible. Proper firing is of the utmost importance. It is very difficult to secure men who fully understand the great variety of conditions to be considered in burning, and one of the most common failures in this part of the work is due to uneven firing. In the North Dakota clays of this character, which are usually rather refractory, there is a tendency to underburn.

The regulation of oxygen in the kiln greatly affects the color of the ware. The brighter shades can only be secured in the oxidizing fire. Kilns are frequently fired with too little oxygen, especially during the last stages. The result is a dead and unsatisfactory color.

Great care must be taken in sorting the brick. Different shades will be found in different parts of the same kiln. These should be sorted so that bricks of light shades will be accummulated as successive kilns are fired. A stock of these shades should always be kept in order to give uniformity in color. Slight variations in tint in a building will greatly reduce the artistic effect, no matter how good the brick may be.

There are several localities in North Dakota where excellent pressed brick clay is found. Among these may be mentioned the following. It is not, however, to be understood that the brick will

be of the same quality in these various localities. While clays mentioned will make good pressed brick, the character of the brick will vary greatly not only on account of the composition and properties of the clay but also on account of the difference in the manufacturing. Often the best clays are so poorly handled that the product is hardly admissible, while in the hands of a more skillful manipulator a poorer clay may give a much better product.

Excellent pressed brick is now made at Dickinson, Stark county, where the high grade white-burning clays are used as a body mixed with clay nearer the surface, which gives the red shades. The white clays are of exceptionally fine quality, some of them being so pure that they are fit even for white earthenware. They are also strongly refractory. With proper handling, a variety of high grade products can be made from these clays. They are for the most part strongly plastic, and this quality should be taken into consideration in the manufacturing process adopted. Best products can only be gotten by strong firing. The analyses of some of these clays are as follows:

Analyses of Pressed Brick Clays at Dickinson.

	Per Cent.	Per Cent.	Per Cent.
Silica	66.55	56.03	64.22
Alumina	23.22	24.23	17.22
Iron oxide	1.16	9.46	2.09
Lime	0.29	....	....
Magnesia	0.61	0.31	0.37
Potash	....	0.09	0.21
Soda	....	0.72	0.34
Loss by ignition	7.09	9.39	10.29

Very excellent brick similar to the Dickinson brick is being made at Hebron. Here also there are varieties of high grade clays which can be utilized for many different products. The clays at Hebron and Dickinson are very similar.

A pressed brick plant has been established near Walhalla where the Benton clays are utilized. This brick is of a light red color.

At Wilton and at Kenmare the Laramie coal clays have been utilized for the production of a red brick. There are several other localities where there is, no doubt, material for pressed brick. A portion of the Pierre shales in some localities will make good pressed brick.

Clays fit for pressed brick appear at the north end of Davis Butte, north of Dickinson (sample No. 2501). Also about ten miles

south of Dickinson along Antelope creek (sample No. 1103). This clay gives a strong, mottled brick. The analysis is as follows:

ANALYSIS OF SAMPLE No. 1103.

	Per Cent.
Silica	67.60
Alumina	16.32
Iron oxide	2.82
Lime	3.45
Magnesia	0.51
Loss on ignition	7.07

In Chalk Buttes, Billings county, a pressed brick clay (No. 408) is found. The analysis is as follows:

ANALYSIS OF SAMPLE No. 408.

	Per Cent.
Silica	65.16
Alumina	19.16
Iron oxide	3.32
Lime	1.04
Magnesia	1.75
Loss on ignition	4.83

In Black Butte, Hettinger county, two or three pressed brick clays are found. (See samples Nos. 2102 and 2104.) The analysis of the latter follows:

ANALYSIS OF SAMPLE No. 2104.

	Per Cent.
Silica	60.98
Alumina	26.24
Iron oxide	1.34
Lime	0.34
Magnesia	0.94
Potash	1.26
Soda	1.22
Loss on ignition	7.85

In the buttes north of the railroad between Glandstone and Dickinson pressed brick clays may be found. The analyses of two of these (Nos. 2402 and 2403) clays are as follows:

ANALYSIS OF SAMPLE No. 2402.

	Per Cent.
Silica	65.70
Alumina	22.07
Iron oxide	1.33
Lime	0.23
Magnesia	0.36
Loss on ignition	6.90

ANALYSIS OF SAMPLE NO. 2403.

	Per Cent.
Silica	65.03
Alumina	23.16
Iron oxide	1.00
Lime	0.29
Magnesia	0.44
Loss on ignition	7.21

Facing brick clays are found about three miles west of Hebron in the buttes. (See samples Nos. 3001, 3002, 3004.) Similar material is also found in the buttes seven miles northeast of Hebron (sample No. 3104). In Billings county, in the divide between the Knife and Little Missouri rivers, pressed brick clay is found, as seen by samples Nos. 3702 and 3703, the analyses of which are given here:

ANALYSIS OF SAMPLE NO. 3702.

	Per Cent.
Silica	66.22
Alumina	20.51
Iron oxide	3.49
Lime	0.23
Magnesia	0.78
Potash	....
Loss on ignition	6.83

ANALYSIS OF SAMPLE NO. 3703.

	Per Cent.
Silica	62.65
Alumina	20.76
Iron oxide	4.98
Lime	0.26
Magnesia	0.77
Loss on ignition	6.55

Along the Little Missouri river near Manning's ranch, Dunn county, there are several clays which will produce good pressed brick, particularly those described as samples Nos. 3903, 3904, and 3911, the analyses of which follow. Nos. 3904 and 3911 make deep reds.

ANALYSIS OF SAMPLE NO. 3903.

	Per Cent.
Silica	65.98
Alumina	20.68
Iron oxide	3.82
Lime	0.29
Magnesia	0.41
Loss on ignition	7.60

ANALYSIS OF SAMPLE No. 3904.

	Per Cent.
Silica	53.32
Alumina	23.76
Iron oxide	9.30
Lime	0.25
Magnesia	1.26
Potash	2.10
Soda	0.10
Loss on ignition	8.50

ANALYSIS OF SAMPLE No. 3911.

	Per Cent.
Silica	56.42
Alumina	16.93
Iron oxide	7.47
Lime	2.61
Magnesia	3.16
Loss on ignition	7.58

In Goodman valley, Mercer county, there is some facing brick clay. Sample No. 4011 gives a good red.

It will thus be seen that there are several localities which furnish a variety of clays suitable for pressed brick. Of course the brick will vary much in character and range from nearly white to a deep red. These clays are found in the Benton and Pierre shales. Laramie clays are usually associated with the coal and the Tertiary clays lie above the coal. Those of the Teritary are of the highest grade, the white clays running into fine pottery clay.

PAVING BRICK CLAYS.

Paving brick clays are not nearly as abundant as people commonly suppose. No paving brick has as yet been made in this state. There are, however, several localities in which a suitable paving brick clay is found.

Paving brick is made by the plastic process and commonly by the ribbon auger machine, and therefore demands a clay which is sufficiently plastic to be easily molded and which is fine grained enough to bond thoroughly during the firing. In order to secure durable brick for extreme variations in temperature and for hard traffic in streets it is necessary to have a dense, hard body, but not one which is brittle. In order to secure these results it is necessary to have in the body of the clay material which will begin to fuse at a rather low temperature, but there must be a wide range between incipient fusion and complete vitrification. It is frequent-

ly impossible to secure this range without mixing clays. The color of the product is not so important, but it is usually some shade of red.

Much lime and magnesia are to be avoided since they render the brick brittle. Considerable care is required in the burning to get a uniformly hard product. The following table is given by Wheeler to indicate the range and composition of paving brick clays:

Table Showing Range and Composition of Paving Brick Clays.

	Minimum Per Cent.	Maximum Per Cent.	Average Per Cent.
Silica	49.0	75.0	56.0
Alumina	11.0	25.0	22.5
Iron oxide	2.0	9.0	6.7
Lime	0.2	3.5	1.2
Magnesia	0.1	3.0	1.4
Potash	1.0	5.5	3.7
Soda			
Loss by ignition	3.0	13.0	7.0

It will be seen from the average that these clays are usually rather rich in aluminum and iron; not high in lime or magnesia but containing a considerable amount of potassium and sodium. As will be seen by the analyses to follow of clays from different places in North Dakota, there are a few paving brick clays which fall well within the limits suggested by Wheeler.

Associated with some of the coal along the Missouri river, in Mercer county, there are layers of bluish gray clay, fine in texture and easily molded, which baked to a very hard, tough paver. A similar clay is found in Ward county, located near the coals. It is a very plastic blue clay. Its shrinkage is high but by proper methods it could no doubt be handled without great difficulty. It is not, however, as easy to handle in the manufacturing process as could be desired. It bakes to a deep red and has a hard, tough, vitrified body. The writer has made several paving brick tests on this clay. The analysis of this clay is as follows:

Analysis of Clay Suitable for Paving Brick.

	Per Cent.
Silica	56.86
Alumina	25.03
Iron oxide	6.11
Lime	0.71
Magnesia	0.76

	Per Cent.
Potash	0.50
Soda	0.016
Loss by ignition	10.014

A most excellent paving brick can be made from one of the clays found along the Little Missouri near Manning's ranch, in Dunn county. (See sample No. 3911.) This gives a fine, tough red paver. The analysis of the clay is as follows:

ANALYSIS OF PAVING BRICK CLAY NEAR MANNING'S RANCH, DUNN COUNTY.

	Per Cent.
Silica	56.42
Alumina	16.93
Iron oxide	7.47
Lime	2.61
Magnesia	3.16
Potash	....
Soda	....
Loss by ignition	7.58

A paver might possibly be made from some of the clay at Mandan. (See sample No. 6601.) One of the clays found in the Black Buttes north of Sandcreek, Billings county (sample No. 408), would doubtless produce paving brick. The analysis of the clay is as follows:

ANALYSIS OF SAMPLE NO. 408.

	Per Cent.
Silica	65.16
Alumina	19.16
Iron oxide	3.32
Lime	1.04
Magnesia	1.75
Loss by ignition	4.83

One of the clays found in the Hebron Brick Company's deposit (No. 2901) could no doubt be used for a paver. It is possible also that one of the clays found near the coal mine near Richardton might make a paver of questionable quality. The same may be said of one of the clays associated with the coal of Black Butte and one or two other localities.

Although there is no paving brick made in North Dakota at the present time, there is beginning to be a demand for such material and, on account of the character of the soil and drainage, it will be necessary as the cities grow larger to do considerable paving. It does not seem improbable that the time will soon come when some of the deposits mentioned as suitable, if not too far from the railroad, could be advantageously developed for paving brick.

REFRACTORY MATERIALS.

Refractory materials embrace a great variety of clay products possessing the quality of resisting high temperatures. The importance of this material is increasing rapidly with our industrial development. Good refractory material is used for a great number of purposes and in increasingly large quantities. The following serve to illustrate some of these numerous uses: For fire brick, retorts for gas works, stove linings, glass works, metal works, crucibles, fire proof buildings, furnaces, ovens, flues, fire proof safes, etc.

Refractory products used for the purposes mentioned must be infusible at the temperature required in these operations and they must not soften, swell or crumble, but must keep their shape even after frequent heating to a high temperature and subsequent cooling.

It often happens that very refractory materials do not resist abrasion well or the chemical action of furnace gases. But no one kind of refractory material is good for all purposes. Careful attention must be paid to the selection of raw material and the manufacture of fire clay products so as to meet the particular uses to which the refractory product will be put. A good fire brick, for example, for the lining of a gas furnace might not be at all satisfactory for a boiler setting or a kiln, which would be subject to abrasion or fluxing action. Moreover, a fire brick which would be entirely satisfactory for a furnace smelting acid or quartz ores would not be at all suitable for furnaces smelting highly basic ores.

The term refractory, therefore, is conditional to some extent upon the use. It will be seen that in some cases for example a highly silicious brick may be desirable while in other cases the reverse would be preferable.

FIRE BRICK CLAYS.

The manufacture of satisfactory fire brick products demands not only high grade raw material but also great care and skill in making: A thorough knowledge of the chemical and physical properties of a clay will enable us to form a very good idea as to the fitness of the clay for refractory products. While the composition of fire clay may vary somewhat, it should be essentially a pure silicate of aluminum and it is generally slightly quartzy in character. Pure kaolin fuses at a very high temperature, at about cone 36 or 3362 degrees F. Therefore the addition of impurities to a pure kaolin reduces its refractoriness. The impurities most com-

monly found are iron, lime and the alkalies, which form more or less active fluxes. Additional silica does not reduce the resisting power of fire brick at moderately high temperatures, but at extremely high temperatures the addition of silica shows a marked fluxing tendency.

It is often supposed that sandy fire clays are higher refractory material than those with less silica. This idea is no doubt derived from the fact that the sand grains render the brick less dense and therefore less affected at ordinary temperatures. The effect is produced not by the presence of silica so much as by the porous condition in which the brick is left. Clay of the same composition, ground to a powder, shows much lower refractory power. In order to secure this porosity without the addition of silica, pure hard-burned fire clay may be ground coarsely and added as grog to a body of plastic high grade fire clay. When such a brick is burned the plastic material bakes to a strong, well bonded body, while the grog gives the porosity required. Plasticity is a very desirable quality provided the shrinkage is not too great and the density can be overcome by grog.

The texture of fire clay products certainly exerts a marked influence upon refractoriness. This is frequently noticeable when clays of nearly the same chemical composition show marked differences in their fire resisting qualities. This difference will depend upon the variation in the size of the grains or the texture of the clay.

Experience has proven that the best refractory wares, in a general way, are those which are strong enough to resist reasonable abrasion but which contain sufficient coarse grained refractory material to allow the brick to remain porous or slightly spongy even at high temperatures, and yet retain firmness and strength of body sufficient to carry the weight imposed upon it. This is particularly true where heating is rapid and the surfaces are liable to be suddenly cooled.

There is little doubt but that this character of fire brick can be better obtained from the use of a good plastic fire clay properly grogged than from the use of a natural sandy fire clay. While the sandy clays burn porous and are able to resist moderately high temperatures, they will not stand excessively high temperature nor the action of liquid slags. (See table of physical tests.)

The essential qualities of fire clays are plasticity, great freedom from lime, and the fusing constituents, iron, and the alkalies, soda

and potash. Iron may exist in clays in several forms; for example, as peroxide, protoxide, sulphate and sulphide. But, in whatever form, unless in small quantities, it is revealed by the ordeal of heat in the color and the tendency to melt. The amount of iron which a fire clay can stand depends largely upon the lime, potash and soda it has. A clay containing only traces of these fluxing constituents may have from 3 per cent to 5 per cent of iron and still possess considerable fire-resisting power. If, however, a small proportion of lime and alkalies is added, the clay is useless as fire clay.

Lime and magnesia evidently exert a considerable influence upon the fusibility of clay. There has been some difference of opinion among chemists on this point. It has been said that the best fire clays seldom contain more than one per cent of lime and magnesia together. Potash and soda are doubtless the most powerful fluxing contstituents commonly found in clays. They unite readily with silica, forming the alkaline silicates which bring down the fusing point to a much lower temperature. There is some difference of opinion in regard to the amount of alkalies a good fire clay will stand. Snelus says that about one per cent (of potash) is sufficient to render them unsuitable at high temperatures. Bischof found that four per cent of potash, in a silicate of alumina without any other bases, could be fused at the melting point of wrought iron. The most carefully made analyses of the more noted and best fire clays of this country and Europe, do not generally show more than two per cent of alkalies. From the analyses of the fire clays of New Jersey it appears that those which are found to have one and a half to two per cent and upwards of potash have not proved to be good fire clays.

The amount of alkalies admissible in a fire clay depends largely upon the purity, and probably upon the physical condition of the clay. Clays having much lime and magnesia or iron, can stand but little potash and soda. In a general way it may be said that a fire clay should not contain above five per cent of iron and alkalies together. A pure open body or coarse clay will probably stand more alkalies than it would if in other condition. What has been given may be regarded as covering the most essential characteristics of fire clays. The only way to get a safe determination of the nature and value of a given clay is to consider the clay as a whole, the resultant of the action of all its properties.

High grade fire clays are not very abundant but there are a few localities in the state where excellent deposits of fire clays are

found. These are practically all in the southwestern part of the state on the higher levels, in the Tertiary formation, above the coal

About Dickinson, Stark county, there are several clays which may be considered first quality fire clays. It has already been stated that they are found in the Tertiary formation. The finest clays in this locality occur in elevations 100 feet or more above the surrounding valley. These clay knolls have escaped much of the erosion to which the surrounding country has been subjected. If these deposits ever extensively covered the plain far east of Dickinson they have probably been mostly or entirely removed by the longer action of the receding water, glacial or post-glacial, as it narrowed to the present basin of the Missouri river. The ultimate source of these deposits is a source for conjecture. It is not impossible that they were once feldspathic rocks occurring to the west and northwest along the flank of the Rocky Mountains.

The clays of this character which the writer has examined about Dickinson, outcrop near the top of high bluffs. In some cases the surface soil and clay seem to have been entirely washed away and the white fire and earthenware clay is left capping the bluff. This is the case with a deposit of very fine clay which occurs about one mile south of Dickinson. At this point the bluff is about 100 feet high. The base appears to be principally of fine sand and clay. Above this is a very thick layer, probably from ten to fifteen feet, of fine white fire clay; above this is a layer perhaps four feet thick of still purer white clay, which caps the hill where not washed away. This upper clay is intimately mixed with a small amount of sand, which gives it a rough feel. As taken from the layer, the lumps are soft enough to be crushed in the hand. When baked it produces a hard body which shows no tendency to fuse. The color becomes a pure white, purer than before baking, which indicates that a small amount of carbonaceous matter is present in the unbaked material. An analysis of this clay shows the following:

ANALYSIS OF FIRE CLAY AT DICKINSON.

	Per Cent.
Silica	72.66
Alumina	17.33
Iron oxide	1.05
Lime	0.13
Magnesia	....
Potash	0.36
Soda	0.38
Loss on ignition	9.35

From the analysis it will be seen that this is a very pure clay. The silica appears rather high in proportion to the aluminum, but this is due to the presence of a small amount of sand which, if necessary, could be removed with little trouble. For most purposes the silica does not appear too high. The iron, it will be noticed, is very low, while there is scarcely more than a trace of lime, and the alkalies are also low. In all respects this clay seems to be an exceedingly fine fire clay.

The clay, as has been stated, found immediately under this, is a layer about ten feet thick. It is very fine and free from grit, and can be dug with a spade and pulverized in the hand. Its color when dug is a grayish white probably due to a slight amount of carbonaceous matter, but after burning it becomes a pure white. It has a very firm homogeneous body, and when baked becomes very hard with a clear, sharp ring. This clay has been subjected to intense heat in the laboratory furnace and stands perfectly without cracking or warping. The analysis of a sample taken from a surface exposure gives:

ANALYSIS OF FIRE CLAY FROM DICKINSON.

	Per Cent.
Silica	64.84
Alumina	24.31
Iron oxide	1.60
Lime	0.11
Magnesia	0.24
Potash	trace
Soda	0.32
Water and volatile and other matter	8.58

This analysis shows a very pure clay and one well proportioned for immediate use. The fluxing constitutents are so small in amount as hardly to need notice. The iron is also small for an *unwashed surface* specimen. There is no doubt but that this clay, as well as the one mentioned before, is unusually well suited for the highest grade of fire material. Both of these clays are used by the Dickinson Fire and Pressed Brick Company.

Some of the clays used by the Hebron Brick Company, illustrated by samples No. 2905 and 2909, are undoubtedly good fire clays. The following is an analysis of sample No. 2905:

ANALYSIS OF SAMPLE NO. 2905.

	Per Cent.
Silica	73.90
Alumina	16.49
Iron oxide	1.25
Lime	0.29
Magnesia	0.46
Potash	1.20
Soda	0.22
Loss on ignition	5.52

A fuller description of this deposit and the factory of the Hebron Fire and Pressed Brick Company, which makes use of this clay, will be found in another place.

At Black Butte, Hettinger county, a clay, No. 2104, would make a fair grade refractory material. The analysis is as follows:

ANALYSIS OF CLAY FROM BLACK BUTTE, HETTINGER COUNTY.

	Per Cent.
Silica	60.98
Alumina	26.24
Iron oxide	1.34
Lime	0.34
Magnesia	0.94
Potash	1.26
Soda	1.22
Loss on ignition	7.85

The following clays might also be used for fire brick. Nos. 2607 and 2608, from buttes about ten miles northeast of Dickinson:

	No. 2607. Per Cent.	No. 2608. Per Cent.
Silica	70.27	75.65
Alumina	20.81	17.85
Iron oxide	0.33	0.49
Lime	0.23	0.23
Magnesia	0.26	0.18
Potash	....	0.88
Soda	....	trace
Loss on ignition	6.38	5.31

It is possible that clay No. 2610 (from the same locality as Nos. 2607 and 2608), No. 4803 from Davis Butte near Dickinson, and No. 4005 from Goodman Valley, Mercer county, would also be suitable for fire brick. They stood the physical tests very well, but as chemical analyses were not made it is impossible to speak with certainty in regard to them.

The following table of analyses of a number of fire clays from different parts of the world and extensively used for various refractory purposes will serve as a means of comparison with North Dakota clays:

TABLE "A."—ANALYSIS OF FIRE CLAYS FROM VARIOUS LOCALITIES.

CONSTITUENTS.	No. 1—New Jersey. (Used extensively)	No. 2—Dowlais, South Wales.	No. 3—Newcastle on Tyne.	No. 4—Newcastle on Tyne.	No. 5—Stourbridge, England.	No. 6—Frankenthal on Rhine, Germany.	No. 7—Cheltenham, Missouri.	No. 8—New Jersey, (Middlesex district.)	No. 9—Cornwall or Devonshire fire-brick
Silica	74.30	67.12	69.25	48.55	63.40	50.00	50.80	45.60	73.50
Alumina	18.11	21.18	17.90	30.25	31.70	31.69	31.53	38.40	22.70
Iron oxide	1.09	1.85	2.97	4.06	3.00	2.54	1.92	1.20	1.70
Lime	0.11	0.32	.....	1.66	.....	.....	.....	0.22	
Magnesia	.....	0.84	1.30	1.91		.....	trace	0.25	*2.10
Potash	0.76	2.02	.....	.....	*1.90	2.22	0.40	0.59	
Soda	0.20	.....	.....	.....		.....	.....	.....	
Water and volatile matter	5.90	7.11	7.50	10.67	.....	12.65	13.80	13.80	.....
Other matter	.....	.....	.....	.....	.....	0.90	1.50	.....	.....

*Alkalies, waste, etc.

TABLE "B."—ANALYSES OF NORTH DAKOTA FIRE CLAYS.

CONSTITUENTS	No. 1—Dickinson (upper)	No. 2—Dickinson (under No. 1.)	No. 3—Dickinson	No. 4—Hebron.	No. 5—Black Butte, Hettinger Co.	No. 6—Buttes 10 miles northeast of Dickinson	No. 7—Buttes 10 miles northeast of Dickinson
Silica	72.66	64.84	64.22	73.90	60.98	70.27	75.65
Alumina	17.33	24.31	17.22	16.49	26.24	20.81	17.85
Iron oxide	1.05	1.60	2.09	1.25	1.34	0.33	0.49
Lime	0.13	0.11	trace	0.29	0.34	0.23	0.23
Magnesia	.....	0.24	0.37	0.46	0.94	0.26	0.18
Potash	0.36	trace	0.21	1.20	1.26	.....	0.88
Soda	0.38	0.32	0.34	0.22	1.22	.....	trace
Loss on ignition	9.35	8.58	10.29	5.52	7.85	6.38	5.31

In making comparisons of the analyses of the clays it must be remembered that in all cases the North Dakota clays were unwashed, and in most cases as dug from surface exposures. By reference to the tables of analyses it will be seen that the clays of North Dakota compare very favorably with many of the high grade fire clays extensively used in other parts of the world. In several cases it will be seen that North Dakota clays are purer and would doubtless produce superior fire clay products if properly treated.

When we consider the quality of the clays, the ease with which they can be mined, their abundance and the almost inexhaustible supply of cheap coal near the most of them, the surrounding markets and the means of transportation at hand in some cases, there seems to be no reason why these clays, especially those now being worked, should not in time become the basis of an extensive and profitable industry.

SEMI-POROUS WARE.

Semi-porous ware includes drain tile, flower pots, red ware, etc. Most of the coarser grades of this ware may be made from the higher grades of brick clay, but the best of such material is a little more exacting in the clay demanded. Clays fit for high grade articles of this kind should possess sufficient plasticity and tenacity to be readily molded into various shapes and the product should have strength enough to resist too easy crushing. They must have enough quartz material to prevent cracking and shrinking. The material should contain but little lime, for if present in considerable quantities it affects the porosity, durability and color of the product. This is particularly true with reference to its use for red ware.

A clay suitable for this kind of material must be free from excessive shrinkage or cracking in drying or in burning, and it must be sufficiently plastic to form readily in the mold or machine.

Drain tiles, other conduits, and hollow bricks are usually made by the plastic process and an auger machine, and for this purpose the clay must not be too brittle, neither must it be sticky, in which case it is difficult to clear the machine. Such difficulty may frequently be avoided by mixing with the clay varied proportions of fine sand or finely ground burned clay, the latter usually giving preferable results. The use of this finely ground grog will also greatly modify the shrinkage and porosity.

If the material is to be used for glazed red ware, such as is sometimes used for cooking utensils, it will be necessary to determine whether the clay will take a glaze and, if so, at what temperature the bisque should be burned. Sometimes this porous hollow ware is made into semi-fireproof material, and in such cases the clay should be reasonably refractory. The character of clays adapted to this use is well illustrated by the following tests and chemical analyses of two New Jersey clays, used for this purpose:

Air shrinkage	Tensile strength	Fire shrinkage		Color	Hardness
5 per cent	145 lbs.	Cone 03	1.6 per cent	gray—red	not hard
		Cone 01	2.0 per cent	red	hard
		Cone 3	2.9 per cent	red	hard
		Cone 15 to 16			viscous

ANALYSES OF TWO NEW JERSEY CLAYS.

	1.	2.
Silica	52.22	60.18
Alumina	29.43	23.23
Ferric oxide	2.78	3.27
Lime	0.88	1.00
Magnesia	0.72	0.67
Potash	2.10	2.58
Soda	0.75	0.80
Loss on ignition	11.10	8.54
	99.98	100.27

1. Clay from bank of Natural Fire-proofing Company, Keasbey, N. J.
2. Clay from Sayre & Fisher's pit, Sayreville, N. J.

The highest grade of material of this kind can be made from many of the semi-plastic or semi-refractory Tertiary clays which are not sufficiently pure to be used for pottery. This is particularly true of the many clays found in Stark and Hettinger counties. The Pierre shales in some localities may also be utilized for these purposes. This grade of ware can be made from some of the clays of the following localities:

At Minot, Ward county, on the main line of the Great Northern railway, one or two very good clays are found associated with the coal of that locality. A few miles northeast of Minot coal is mined from the bluffs that rise from the old valley of the Souris river At one place the coal is found in a nearly horizontal layer, probably eight to twelve feet thick and about twelve feet below the top of the bluff. Most of the covering material above the coal appears to be clay and sand. Just above the coal there is a layer of fine clay of a slaty color and smooth, greasy feel. The layer appears to be several feet thick. This clay would probably make an excellent architectural material for the finer ornamental purposes. With a proper admixture of sand it might be used for drain and sewer pipe. In the laboratory it bakes to a light reddish cream and becomes very firm. Its composition is shown by the following analysis:

	Per Cent.
Silica	56.86
Alumina	25.03
Iron oxide	6.11
Lime	0.71
Magnesia	0.76
Potash	0.50
Soda	0.016
Water and volatile matter	10.014

In Mercer county at an old coal mine on the Missouri river a clay is found associated with the coal which is very similar to the Minot clay. It has about the same texture, color and feel and after being baked looks much the same. It could therefore be used for the same purposes as the Minot clay. The analysis of this clay is as follows:

	Per Cent.
Silica	60.79
Alumina	16.23
Iron oxide	4.49
Lime	0.65
Magnesia	1.02
Potash	0.19
Soda	0.28
Other matter by subtraction, water and volatile matter	16.35

Clay taken from the brick yards at Burlington, Ward county (sample No. 5602), appeared fairly well suited for common drain tile.

One of the clays found at Wilton (No. 6502) could be used for the manufacture of common porous ware such as flower pots and possibly porous drain tile.

At Bismarck, along the bank of the river near the Northern Pacific railroad bridge, there are two layers of clay both of which may be used for the purposes described in this section. These two clays occur about fifty feet above the river. The upper layer is several feet thick, is of a dark gray color and is mixed with a little finely pulverized sand. Just under this is a finer, more plastic, chocolate-colored clay of uniform texture. The color is due in part to the presence of carbonaceous matter. On burning, it becomes a light red. When baked, it possesses a hard, compact, ringing body. The thickness of the layer is not known, but of the two layers there is probably a deposit of not less than six or eight feet. There is but little doubt that this clay would be of value for several uses. It could be mixed with the clay above which is much like it and

would then probably make drain and sewer pipe and a good ornamental building material. An analysis of this clay shows:

ANALYSIS OF LARAMIE CLAY FROM BISMARCK.

	Per Cent.
Silica	58.73
Alumina	14.98
Iron oxide	5.63
Lime	2.10
Magnesia	0.74
Potash	0.16
Soda	0.988
Water and volatile matter and other matter by subtraction	16.672

Certain layers of the clays which outcrop in buttes about nine miles southwest of Dickinson are well suited for the production of drain tile. For example, clays No. 803 and 804. (See table and description.) The following is an analysis of clay No. 803. This analysis is an average of three feet, but the adjoining clay is probably quite similar:

ANALYSIS OF SAMPLE NO. 803.

	Per Cent.
Silica	66.48
Alumina	19.55
Iron oxide	2.49
Lime	0.84
Magnesia	1.16
Loss on ignition	7.45

The clay in association with the coal north of Heart Butte, as described under sample No. 1802, may also be used for drain tile and similar purposes. Clay No. 2104 from Black Butte, Hettinger county, described in Part III, would no doubt make good drain tile. Analysis of this clay is as follows:

ANALYSIS OF CLAY (NO. 2104) FROM BLACK BUTTE.

	Per Cent.
Silica	60.98
Alumina	26.24
Iron oxide	1.34
Lime	0.34
Magnesia	0.94
Potash	1.26
Soda	1.22
Loss on ignition	7.85

Some of the clays which outcrop along the Little Missouri river, particularly those seen near Jim Creek, Dunn county, are well suited to the manufacture of hard, red drain tile. The following is an analysis of sample No. 3904 from this locality:

ANALYSIS OF SAMPLE NO. 3904.

	Per Cent.
Silica	53.32
Alumina	23.76
Iron oxide	9.30
Lime	0.25
Magnesia	1.26
Potash	2.10
Soda	0.10
Loss on ignition	8.50

North of Rocksprings, Dunn county, two samples of clay tested and described as No. 4402 and No. 4405 are both well adapted for the manufacture of flower pots and similar ware. Clay from Davis Buttes (described as No. 4802) could be used for flower pots and similar purposes.

In the buttes about two miles north of Gladstone an excellent material for drain tile, flower pots and other purposes is found. (See reference to No. 3502 in table of physical tests and in local descriptions in Part III.) An analysis of this clay is as follows:

ANALYSIS OF SAMPLE NO. 3502.

	Per Cent.
Silica	65.64
Alumina	22.74
Iron oxide	1.66
Lime	0.29
Magnesia	0.61
Potash	1.46
Soda	1.76
Loss on ignition	6.15

About Dickinson there is a great variety of clays, some too poor for earthenware and fine refractory material, which will make good semi-fire brick and other inferior refractory articles, besides tiles, pipes and the finest ornamental building material. By mixing the clays found in this vicinity, material can be had for a large number of uses. A mottled clay, said to occur in large quantities, seems remarkably well suited to the manufacture of terra cotta and ornamental material. This clay appears very much like some of the mottled clay from Martha's Vineyard. It has a fine white body

dotted with patches of red. It is all very free from grit and when ground makes a uniform body of light red color. It is very plastic, but stands heat well without cracking or warping. The following is an analysis of this clay:

ANALYSIS OF MOTTLED CLAY FROM DICKINSON.

	Per Cent.
Silica	56.03
Alumina	24.23
Iron oxide	9.46
Lime	....
Magnesia	0.31
Potash	0.088
Soda	0.72
Water and volatile matter	9.39

This clay will be seen to be remarkably free from all fusing constituents excepting iron. By properly mixing with the fine white clay found in the same locality (described under fire and earthenware clays) a fairly refractory material would be gotten, fit for some grades of semi-fire brick, saggars and many other purposes.

About Dickinson and Hebron and in other places in this locality there are clays of excellent quality for drain tile, flower pots and a variety of such ware, but the clays in these places are probably more valuable for other purposes.

In this region higher grade clays abound which are too valuable to be used for the purposes named in this division. These will be considered under fire and earthenware clays.

For comparison, we insert the following analyses of clays of this character found in other localities, and used for the purposes we have just considered:

ANALYSES OF CLAYS USED FOR SEMI-POROUS WARE.

CONSTITUENTS	No. 1—Wakerly buff clay.	No. 2—Watcombe red clay.	No. 3—Brosley red clay.	No. 4—Dunfermline red clay.	No. 5—Saggar Marl Staffordshire Potteries.	No. 6—Rockingham and brick clay.
Silica	69.59	57.83	64.06	64.14	54.38	58.07
Alumina	20.04	20.55	20.60	13.34	26.55	27.38
Iron oxide	3.37	7.75	7.16	7.57	8.38	3.30
Lime	3.16	1.68	0.12	1.90	.....	0.50
Magnesia	3.18	0.97	0.04	.....	.....	.....
Potash	.....	3.87	0.91	1.54	.....	10.30
Soda	.....	0.56	0.44	.....	.....	
Water, organic matter and loss	.....	6.52	5.85	.....	7.28	
Other constituents	.....	0.90	0.71	.....	3.14	.....

The following are analyses of North Dakota clays thought fit for drain tile, terra cotta, etc.

ANALYSES OF NORTH DAKOTA CLAYS SUITABLE FOR SEMI-POROUS WARE.

CONSTITUENTS	Minot clay, above coal.	Coal mine, Mercer Co., on Missouri river.	Near Bismarck, on bank of Missouri river	Dickinson buff clay.	Buttes nine miles southwest of Dickinson.	Black Butte, Hettinger Co.	Buttes two miles north of Gladstone.	Banks of Little Missouri, at Manning's ranch.
Silicia	56.86	60.79	58.73	56.03	66.48	60.98	65.64	53.32
Alumina	25.03	16.23	14.98	24.23	19.55	26.24	22.74	23.76
Iron oxide	6.11	4.49	5.63	9.46	2.49	1.34	1.66	9.30
Lime	0.71	0.65	2.10	.....	0.84	0.34	0.29	0.25
Magnesia	0.76	1.02	0.74	0.31	1.16	0.94	0.61	1.26
Potash	0.50	0.19	0.16	0.09	.....	1.26	1.46	2.10
Soda	0.02	0.28	0.99	0.72	.....	1.22	1.76	0.10
Loss on ignition	10.00	16.35	16.67	9.39	7.45	7.85	6.15	8.50

By comparing the analyses of these clays with the preceding analyses given of clays from England and other localities, used for the purposes under consideration, it will be seen that with one or two exceptions the North Dakota clays are of considerably better quality.

In nearly, if not all cases, the clays are easily mined. In most places they are found immediately associated with coal or where it can be had at small cost. This is a great advantage for North Dakota clays. The fuel question is one of paramount importance, since it is one of the largest sources of expense in the manufacture of clay products. The abundance of fuel, which can be gotten for a mere trifle where most of these clays are found, will aid wonderfully in making the manufacture of clay articles an extensive and profitable industry.

The drain tile industry is one which could be very easily and successfully started in several places in North Dakota without the erection of a very expensive plant. If care were exercised in the selection of the clays, some could be found which would work easily and satisfactorily. There should be a growing demand for drain tile in this state and as freight is considerable on such material in proportion to its original cost its extensive use is almost prohibited unless it can be manufactured within the state. A large amount of drainage could very profitably be done in the Red River Valley. If this drainage were properly done it would call for the use of large quantities of drain tile.

STONEWARE.

The clay products grouped under stoneware are, next to brick and refractory material, among the most important of clay wares. The term stoneware is sufficiently broad to admit of the manufacture of a great variety of very widely used articles, such as sewer pipe, floor tile, ornamental wall tile, jars, jugs, etc.

Stoneware is very like a variety of other wares, such as yellow ware, or Rockingham ware, on the one side and lower grade white earthenware on the other. There is of course a great variation in the character of the clay used for stoneware as well as the product. Some of the higher grade stoneware clays, especially the lighter colors, are capable of considerable artistic effect. The cheaper grades of stoneware frequently burn to a red or brown tint.

For the manufacture of sewer pipe the dark-burning clays are not objectionable but for most other products the lighter burning clays are more to be desired. This is particularly true with reference to ornamental tile and dishes.

Most of the clays which are here referred to as fit for stoneware in North Dakota burn to a creamy tint and would be admirably adapted not only to sewer pipe but to the highest grade of stoneware products.

Nearly all stoneware products are made by some plastic process, the auger machine or the plunger mold machine for sewer pipe or turning or molding in some form is commonly employed, therefore the element of plasticity is of much importance. The clay must also bake to a hard, strong body.

In some cases, especially where the ware is to be soft glazed as for sewer pipe and jars, semi-vitrification is desirable, but when the ware is to be glazed with a heavy metallic glaze the bisque should be slightly porous. Clay suitable for this ware should have as its basis a fairly well balanced kaolin. It should not be sandy but should contain a moderately large proportion of alumina. If, however, the alumina is too high and the clay too fine grained, there is too much shrinkage in drying and firing. The matter of shrinkage has to be guarded very carefully, especially in the manufacture of sewer pipe which is made to definite dimensions and required to fit interchangeably. Many clays fail for this purpose in the matter of shrinking and checking.

Clays suitable for the manufacture of stoneware must not only be free from sand but also from pebbles, concretions, fragments of limestone, particles of iron pyrites, etc. For most purposes stone-

ware clays must be sufficiently pure not to need washing or other preliminary treatment. In judging of the fitness of a clay for stoneware, both chemical and physical examinations should be carefully heeded. A chemical analysis is especially important, as it enables one to calculate by means of the silica and alumina whether or not the clay will be likely to take salt glazes or other glazes well. The following analysis of one of the clays extensively used for stoneware will serve as an illustration, although this clay is rather high in its proportion of silica to alumina:

ANALYSIS OF A STONEWARE CLAY.

	Per Cent.
Silica	71.58
Alumina	18.31
Iron oxide	1.09
Calcium oxide	0.40
Magnesia	0.62
Potassium and sodium oxide	2.96
Combined water	5.95

For the purposes of comparison, the following analyses are given of clays used for stoneware in various localities in other parts of the world:

1. Unglazed stoneware, Baltimore, very fine white body.

	Per Cent.
Silica	67.40
Alumina	29.00
Iron	2.00
Lime	0.60
Magnesia	.....
Soda } Potash }	0.60

2. According to Salvetat, fine yellow wedgewood ware consists of:

	Per Cent.
Silica	66.49
Alumina	26.00
Iron oxide	6.12
Lime	1.04
Magnesia	0.15
Potash } Soda }	0.20

3. From analyses of stoneware by the same as No. 2, the following results are secured:

Silica	from	62	to	75	per cent.
Alumina	from	19	to	29	per cent.
Iron oxide	from	1	to	8.5	per cent.
Lime	from	0.25	to	1	per cent.
Magnesia	from	0	to	0.9	per cent.
Soda, Potash	from	0.50	to	1.5	per cent.

By comparing the analyses of stoneware clays from various localities with those of the same class in North Dakota it will be seen that, as far as chemical analyses show, the clays mentioned from this state are apparently of very good quality.

Most stoneware products are fired but once and the glaze is either applied before firing is begun or during the latter part of the burning, so that the fluxing material unites with the clay at a high temperature near the end of the burning. For the lower grade of wares both salt and slip glazing is employed. A great deal of stoneware is salt-glazed on the outside and slip-glazed on the inside, as it is difficult for the salt vapor to reach easily inside surfaces when the kiln is stacked. In salt glazing the ware is burned and the heat of the kiln increased nearly to its maximum and then a definite amount of salt is introduced regularly into the kilns. Along with this there is commonly introduced green or wet wood, which gives the requisite amount of steam to carry the fumes of sodium chloride in such a form that they can penetrate and allow the sodium to unite with the silica and alumina on the surface of the ware. When this has taken place sufficiently the kiln is allowed to gradually cool.

Ware which is slip glazed is coated with a liquid of a fusible clay mixture usually containing considerable iron and alkalies. This slip dries evenly over the body of the ware, which is then fired to the fluxing point of the slip and the clay, when the temperature is gradually reduced.

For ornamental tile and for many kinds of stoneware dishes a heavy white glaze is desired. With the higher grade light colored stoneware clays, particularly such as found in North Dakota, this variety of ware can be secured by using some form of lead glaze.

In North Dakota there are several deposits of excellent stoneware clays. These are usually found in the Tertiary formation in the southwestern part of the state. They are frequently associated with higher grade earthenware clays. In Stark county there are

some such deposits of stoneware clay. At Dickinson this clay lies beneath the white earthenware clay which will be described elsewhere. It is very similar to this earthenware clay but contains a larger amount of impurities, particularly iron. It therefore burns to a hard body a little more easily and takes a yellowish tint. An analysis of one characteristic sample from Dickinson is as follows:

ANALYSIS OF STONEWARE CLAY FROM DICKINSON.

	Per Cent.
Silica	64.22
Alumina	17.22
Iron oxide	2.09
Calcium oxide	trace
Magnesia	0.37
Potassium	0.21
Sodium	0.34
Water and volatile matter	10.29

At Dickinson there are several clays somewhat similar in composition to the one just referred to which would produce excellent stoneware and similar stoneware clays seem also to be found in many of the buttes for some miles around Dickinson. At Davis Butte, north of Dickinson, clay No. 2502 would doubtless make good sewer pipe. Between Gladstone and Dickinson in the buttes north of the railway there is considerable clay suited for sewer pipe, jugs, jars, etc. Samples No. 2402, 2403 and 2405 could be used for these purposes. Sample No. 2402 is found about four feet below the top of the buttes. The analysis is as follows:

ANALYSIS OF SAMPLE NO. 2402.

	Per Cent.
Silica	65.70
Alumina	22.07
Iron oxide	1.33
Lime	0.23
Magnesia	0.36
Loss on ignition	6.93

Three feet below the clay gave the following results:

ANALYSIS OF SAMPLE NO. 2403.

	Per Cent.
Silica	65.03
Alumina	23.16
Iron oxide	1.00
Lime	0.29
Magnesia	0.44
Loss on ignition	7.21

It will be seen from these two analyses of adjoining clays that there is evidently sufficient thickness of this material, and it is certainly of excellent grade, not only for sewer pipe but higher class of stoneware products.

In the buttes ten miles northeast of Dickinson there is clay which could be used for sewer pipe and other stoneware products and also for earthenware. The higher grades of these clays are better than need be for stoneware, but could of course be utilized for that purpose. Samples No. 2602, 2604, 2607 and 2610 could be used for stoneware.

Some of the clays found near Hebron would make satisfactory stoneware. For example, the clay described elsewhere as No. 2909. About three miles west of Hebron in the buttes there are several layers well suited for this grade of ware. They are described in Part III as Nos. 3001, 3002 and 3004. Clay of similar character is also found about seven miles northeast of Hebron and described as sample No. 3104. In the buttes about a mile and a half northeast of Taylor there is a layer about four feet thick of a light-colored clay, No. 3304, which would be well fitted for the manufacture of sewer pipe, jars, jugs, and such products. This clay has the following composition:

Analysis of Sample No. 3304.	Per Cent.
Silica	65.46
Alumina	20.97
Iron oxide	1.83
Lime	0.23
Magnesia	1.14
Potash	1.38
Soda	0.72
Loss on ignition	6.79

In the hills about two miles northeast of Gladstone there is found a deposit of three or four feet or more of a clay almost identical with that just mentioned near Taylor. This clay would also make good sewer pipe, jars, jugs, etc. It has the following composition:

Analysis of Sample No. 3502.	Per Cent.
Silica	65.64
Alumina	22.74
Iron oxide	1.66
Lime	0.29
Magnesia	0.61
Potash	1.46
Soda	1.76
Loss on ignition	6.15

Clays which outcrop in the south end of the buttes known as the Killdeer Mountains, especially such as are represented by sample No. 3802, would probably do for sewer pipe. This opinion, however, is based upon physical tests only, as no chemical analysis was made of this clay. It is therefore impossible to speak with certainty with regard to it.

On the Little Missouri, near Manning's ranch, Dunn county, there is at least one layer of clay which could be used for stoneware products. That is described as sample No. 3906 and there is said to be six or eight feet of this dark, plastic clay. The analysis of this material is as follows:

ANALYSIS OF SAMPLE NO. 3906.

	Per Cent.
Silica	63.19
Alumina	23.35
Iron oxide	1.49
Lime	0.29
Magnesia	0.98
Loss on ignition	7.82

In the analyses and descriptions given it will be seen that there are a number of places in the southwestern part of the state where clays have already been found which will produce excellent sewer pipe, jars, jugs, ornamental tiles, and stoneware of various kinds.

There are no doubt other deposits equally good which have not as yet been located or investigated. By comparing the analyses of stoneware clays already given from other parts of the world with those from North Dakota, it will be seen that the clays mentioned from this state are of good quality and will, no doubt, produce stoneware as good, if not better, than the average of this class of ware.

Many practical tests have been made at the School of Mines on some of these stoneware clays with satisfactory results and in some cases the clays thus tested have been shipped in larger quantities to some of the eastern sewer pipe and stoneware factories and made up into full size sewer pipe and other products. They were found to work very easily in the machine, to dry without undue shrinkage or cracking and to stand firing and glazing satisfactorily. The products were first class in all respects.

Considering the high character of these North Dakota stoneware clays, their proximity to coal, and in some cases nearness to railroads, and considering also the rapidly increasing demand for

stoneware products, especially sewer pipe which is so largely used in the growing cities and towns throughout the state and which from now on will be even more extensively used, there would seem to be a good opportunity for the development of this important phase of the clay industry.

EARTHENWARE.

The term potter's clay is very loosely used to designate a great variety of plastic clays. We shall in this place consider but two divisions of potter's clay, viz., stoneware and earthenware clays. These two clays are those used most extensively for common dishware; the stoneware being the poorer quality and the earthenware, the finer dishware, largely used for tableware. The purest, finest stoneware clays which we have just considered grade insensibly into earthenware clays.

Earthenware clays vary from those approaching nearly to china clay to those so impure (especially from iron) as to be unfit for white ware and called stoneware clays. Clay of this kind containing oxide of iron and alkaline earths in sufficient quantity to make it partially fusible in the heat required to burn it when made into forms and burned is called stoneware clay. The heat is carried far enough to fuse the particles together so that the ware is solid and will not allow water to soak through it, but the fusion has not been carrried so far as to alter the shape of the articles burned. The oxide of iron by the fusion has been combined with the clay, and instead of its characteristic red has given to the ware a bluish or grayish color. Stoneware may be glazed like earthenware, or by putting salt in the kiln, when its vapor comes in contact with the heated ware and makes with it a sufficient glaze. Clay of this kind is used largely for finer grades of jars, jugs, etc.

A considerable variety of products may be gotten by a judicious mixture of fine and inferior clays. The better grades of earthenware clays are occasionally found of sufficient purity to be used in the manufacture of china, porcelain and semi-porcelain wares, while the inferior qualities run gradually into clays used for stoneware, etc. Those clays not sufficiently pure for high grade stoneware may be used in the manufacture of Rockingham and other ware. Stoneware clay may also be used for a very fine quality of drain pipe; but for much of the common drain pipe probably no better than common brick clay is used. Earthenware clay may also be used as a fire clay in many cases and fire clays may in turn be used for

earthware. In fact, the very best fire clays of some districts are practically the same as those used for fine earthenware.

Clays fit for the manufacture of high grade china or to be used in part for making porcelain are among the rarest clays used. For such purposes, material of the utmost purity is required. The clay should be sufficiently plastic to be readily shaped and handled: when baked it must be pure white, or nearly so, and possess reasonable strength. To give these results it must be extremely free from iron and all foreign matter that would affect color. So great freedom from alkalies is not required of porcelain and china clays as for some other purposes, since incipient fusion is necessary to produce the translucency, a characteristic of this kind of ware.

Clays of this kind are found in a few localities only and are then usually mixed with other carefully prepared ingredients. Material is extensively prepared artificially for porcelain and china.

Clays of a slightly inferior grade are those used for the production of the earthenware which constitutes the most of our common white dishware. The best earthenware clays, though not so rare as the china clays, are not very common.

It is upon this kind of clay that the great pottery industry of Staffordshire is built. Soe New Jersey and other clays are now much used in making earthenware. The seat of this industry in New Jersey is at Trenton; in Ohio, at East Liverpool.

Clays for good earthenware must, besides being plastic, be as free from iron as possible, and sufficiently free from alkalies to stand much heat. They should bake white and give a strong, solid body. Most of the requisites are those of a first class white plastic fire clay. The special differences are that an earthenware clay should be freer from iron than it is necessary for a fire clay to be, and that a fire clay should be freer from alkalies than it is needful for an earthenware clay to be. For the action of the various constituents of earthenware clays refer to the discussion of fire clay characteristics.

Clay which is pure white in color and entirely free from oxide of iron may be intimately mixed with ground feldspar or other minerals which contain potash enough to make them fusible, and the mixture still be plastic so as to be worked into forms for ware. When burned, such a composition retains its pure white color, while it undergoes fusion sufficient to make a body that will not absorb water. And its surface can be made smooth and clean by a

suitable plain or ornamental glaze. Ware of this kind is porcelain or china.

The large portion of plain white and decorated wares now sold as C. C. and white granite wares are intermediate between the old earthenware in which the body was of clay unmixed and the porcelain in which the body is of mixed earths that undergo incipient fusion when burned at a high temperature. The fine earthenware of both kinds mentioned above is being improved in quality and appearance each year and approaching nearer in real excellence to porcelain.

White earthenware products are very seldom made from a single clay material. In almost all cases the clay body needs to be modified (or made up by artificial mixing) so as to give the proper whiteness and elasticity, hardness and other properties not usually possessed by a single earthenware clay. Much attention must therefore be paid by the manufacturer of white earthenware to the composition and physical qualities of the clay and to the proper mixing of various ingredients so as to bring the clay to the best working composition. All these ingredients must be as pure as possible.

Two kinds of clays are commonly employed; the higher grade so-called chinaware clays which are difficult to procure but which increase the whiteness of the product, and the ball clay which is usually added to give the necessary plasticity. Fairly pure kaolin or chinaware clay occurs in a few districts in the United States. Some is found in Pennsylvania, Virginia and North Carolina, but even this, when used for higher grades of pottery needs to be carefully selected and washed thoroughly to purify it before being mixed for the potter's use. These china clays are usually of poor plasticity and when used alone show low tensile strength.

The commercial value of earthenware clay depends upon the character of body it produces and to a large degree upon its whiteness. The appearance of the unburned clay cannot be relied upon as a safe criterion of the color of the biscuit. It frequently happens that clay which to the eye seems to be pure burns to a creamy tint, while on the contrary clays darkened by carbonaceous matter often burn to remarkably white ware. But for pottery the ultimate color of a clay cannot be absolutely relied upon without subjecting the biscuit to a test with the glazing material, as the glaze often brings out tints not noticeable in the bisque.

There are so many facts to be considered in the selection and use of potter's clays and mixtures that no detail of composition or character of the raw materials can be overlooked with safety. In

fact the best results are only to be secured after considerable experience with given clays.

While the kaolinite, china clay, or their substitutes used as one portion of the mixture for the finer grades of white ware usually have little plasticity, the ball clays with which this material is mixed are especially plastic. They are fine grained and contain a relatively small percentage of silica but a high percentage of alumina. The iron and other impurities are usually considerably higher in the ball clays. These clays are not only very plastic but give a hard body when burned alone. It is largely because of the plasticity and binding power that these clays are serviceable in the mixture. The following analyses show two clays extensively used as ball clays:

	No. 1 Per Cent	No. 2 Per Cent
Silica	45.39	46.18
Alumina	39.19	39.08
Iron oxide	0.45	1.11
Lime	0.51	0.42
Magnesia	0.29	0.35
Potash, Soda	0.23	0.28
Combined water	14.01	13.04

These clays are usually mixed with more or less finely ground pure flint or quartz material. It is necessary, however, that this also be very free from iron, lime and alkalies. Pure feldspars are sometimes pulverized to form a substitute for a part of the pure clay body. A large proportion of the dishes used for table service and sanitary ware and similar material are known as "C. C.," "Granite," "White Granite," "Ironstone China," etc.

The colors of these wares vary from a slight cream to nearly pure white. Those giving the white color are usually made from purer clays but are not necessarily any better ware. A slight yellow tint may be overcome by the addition of a little cobalt blue.

When the mixture already referred to has been made and the raw material is ready to mold, it contains about the following proportions: 50 to 60 per cent clay substances, 38 to 32 per cent quartz, and 12 to 8 per cent feldspar or corresponding clay. The 50 or 60 per cent clay substance mentioned is frequently made from a mixture of kaolin or chine clay and ball clay. It is very important that all the raw materials used in building up the clay body for pottery be as pure as possible. Most of the clays are not only washed and purified in settling troughs or vats before being sent to the pottery

but are also further purified extensively at the pottery. After the purification process has been completed and the proper mixture made, it is thoroughly agitated by mechanical mixers and when diluted with water to a creamy consistency it is passed through a revolving or other screen covered with fine silk bolting cloth or wire cloth having from 10,000 to 15,000 meshes to the square inch. It is necessary that the mixture be in a very fine condition. If not, a large amount of material will be removed during this screening or bolting process and will therefore modify somewhat the remaining mixture.

The body is now thickened with a similar mixture previously prepared and finely ground. After this tempering it is thoroughly worked till uniform in character and is then ready to be made into ware. All this purifying and mixing process requires great skill, constant attention and a large amount of machinery and space in a pottery.

When the clay has thus been tempered, it is molded or turned (usually molded) into the various shapes required. These are thoroughly dried and fired in the kiln to produce the bisque. The temperature at which the bisque is fired is usaully about cone 8 to 10, that is, 2350 to 2426 degrees F.

Well burned white ware bisque should be hard enough so that it cannot be scratched easily with a steel knife point. The edges should not be too hard. The whole body should have a slight but uniform porosity. If the ware is to be decorated this is next done and the bisque again fired at a low heat. It is then again removed and immersed in a creamy mixture of powdered glaze material. The moisture is absorbed in the ware and evaporates, leaving the glaze powder covering the bisque. The ware is dried and refired with a gradually increasing temperature sufficiently high to melt the glaze and thus cause it to slightly flux with the bisque. The kilns are then gradually cooled and the ware removed.

Earthenware is not subjected to the direct action of the furnace heat, but is fired in muffles or in saggars made of fire clay, piled one upon another, which protect the ware from the action of the flames.

Ornamental decorated and glazed tiles and other ware is made in a similar manner.

Although clays sufficiently pure for white earthenware are comparatively rare, North Dakota is particularly fortunate in having a few beds of clay of this kind of a remarkably fine character. The

writer has made many analyses of these clays and has subjected them to many practical tests at the School of Mines at the University. I have made a great many different products from these clays and in practically all cases the results have been exceptionally satisfactory. Most of the white earthenware clays which are described in the following paragraphs are remarkably fine grained. plastic, easily worked on the potter's wheel or readily molded. There is little tendency to crack in drying or firing and the bisque burns to a white or creamy white body which at the proper temperature takes the glaze with ease.

Some of these clays, as will be seen by referring to the analyses. are remarkable in having a composition very similar to many of the artificially prepared clay bodies after they have been built up to the proper composition, often by several mixtures, as has already been explained. The writer took a sample of an artificially prepared mixture just ready to go to the molds in one of the large eastern factories and analyzed it with the following results:

Analysis of a Prepared Earthenware Mixture.

	Per Cent.
Silica	69.03
Alumina	23.80
Iron oxide	0.45
Calcium oxide	0.29
Magnesia	0.05
Loss on ignition	7.46

By comparing this analysis with the analyses of one or two of the North Dakota clays just as mined, it will be seen that there is a striking similarity in composition, and as might be expected from the analysis, the North Dakota clays referred to made excellent ware without any mixture of outside ingredients.

Samples of this clay were sent away to one or two men who have been for years successfully engaged in practical working with white earthenware clays and products. These people found the clays worked remarkably well without additional mixture. At the World's Fair at St. Louis the School of Mines of the University of North Dakota made an extensive display of products made from North Dakota clays. This display attracted wide attention, especially from those interested in the manufacture of pottery. The white earthenwares made at the School of Mines included the following products: Bisque of cups and saucers, vases, small pitchers, ornamental dishes, small tiles, etc.

Pottery made from the Tertiary clays near Dickinson.

In addition to this the clay was analyzed and the proper kind selected and sent to several of the largest eastern potteries and made into a large pottery display of various kinds. Two full tea sets of beautiful design and excellent quality were produced in one pottery; in another large pottery several pitchers and cups were produced; in another, granite iron ware of various kinds was made. At another of the largest art potteries in the country a fine collection of jardinieres and pedestals was made with a variety of different glazes. Some of these were hand decorated and gave most delicate results. In still another large art pottery a great variety of beautiful vases were made with several different kinds of finishes, all of which worked well. At another place a variety of ornamental designs such as vases, jugs, pitchers, etc., were made with a special white finish for hand decorating. These were afterward decorated by different people and fired with excellent results. Samples of other clays were sent to one or two large ornamental glazed tile manufacturers and excellent tiles were produced. Another variety of clay was sent to a well established glazed brick manufacturer and a first quality enameled brick was produced. In these various establishments the men who worked the clay spoke very highly of its qualities.

The accompanying illustration is taken from a photograph of a single white earthenware set, beautifully decorated, and of a high grade of ware made from North Dakota clays. As will be seen by the description following, only a few of these high grade clays have yet been located in the state. (See Plate XIV.)

In my work with these clays I have invariably started the tests with a chemical analysis. After having selected the clays for various purposes as indicated by the chemical analyses and physical tests, the raw material was worked into various small dishes which were burned in the kilns at the School of Mines. In a great number of tests which the writer has made on these high grade clays there were very few which did not prove by practical tests fully as good as was expected from the chemical and physical tests. In the large number of clays thus selected as suitable for the various purposes, I have had but very few unsatisfactory results. In most cases the clays were plastic, showed only reasonable shrinkage. no trouble from checking in drying or burning. The color was remarkably good without even washing the clays and the bisque took the glaze very satisfactorily.

Material of as high quality as these white earthenware clays is not likely to be found widely distributed and at the present time only a few places are known in North Dakota where workable deposits of such clays occur. More deposits no doubt may be located. Thus far such clays have been found only in the southwestern part of the state, where they are situated in high buttes which have apparently escaped the general leveling of the surrounding country. These white earthenware and fire clays lie in the Tertiary formation above the coal. There is frequently coal found in the vicinity of these deposits, which fact may aid considerably in the future in their profitable development.

In the vicinity of Dickinson, Stark county, clays of this class outcrop near the tops of some of the high buttes. In some cases the surface soil and clays seem to have been entirely washed away and the white clay is left capping the bluff. This is the case with a deposit of very fine white clay about a mile south of Dickinson. At this point the bluff is probably 100 or more feet high. The base of the bluff appears to be chiefly of sand and clay. Above this is a very deep layer, probably from ten to fifteen feet thick, of fine white earthenware clay. This seems to be covered by a layer, perhaps four feet thick, of very pure but slightly sandy clay.

This upper clay as found is of a very light color, but bakes still whiter. It produces a hard body showing little tendency to fuse. An analysis of this clay, as dug, is as follows:

ANALYSIS OF EARTHENWARE CLAY FROM DICKINSON.

	Per Cent.
Silica	73.20
Alumina	18.56
Iron	0.50
Calcium	0.29
Magnesia	0.52
Potassium	0.36
Sodium	0.38
Loss on ignition	5.93

It will be seen from the analysis that this is a very pure clay. The silica appears rather large in proportion to the alumina, but this is due to the presence of a small amount of sand which, if necessary, could be removed, probably with very little trouble. The iron, it will be noticed, is very low for a surface specimen unwashed. The amount of alkalies is small. Withal this clay would, probably with proper treatment, when freed from sand, make excellent earthenware material suited for common white tableware, etc.

The clay which it has been said is found immediately under this, is a layer perhaps from ten to fifteen feet thick. This clay is very fine and free from grit.

It can be dug with a spade and the lumps can be powdered in the hand. The color of the clay as dug is a grayish white, probably due to a slight amount of carbonaceous matter. After baking, it is pure white. It has a very fine homogeneous body. When baked it becomes very hard and has a clear, sharp ring. It stands heat well without warping or cracking. An analysis of a sample taken from a surface exposure, and as dug, gives:

ANALYSIS OF EARTHENWARE CLAY FROM DICKINSON.

	Per Cent.
Silica	66.55
Alumina	23.26
Iron	1.16
Calcium	0.29
Magnesia	0.61
Loss on ignition	7.08

This analysis shows a very pure clay and one which, when washed and purified, seems well proportioned for the potter's use. The fluxing constituents and the iron are not high for an unwashed surface specimen. This clay has been formed into small dishes and baked at a high temperature in the laboratory. The bisque came out a very fine, white, compact body. It had a good ring and showed no tendency to crackle or warp.

In the buttes about one mile north of the railroad track between Dickinson and Gladstone, about a foot and a half or two feet below the top of the butte there is found a layer several feet in thickness of a pure sandy clay which could no doubt be used with excellent results for pottery by removing a portion of the free sand, which could probably be easily done. The analysis of the clay, described as No. 2401, is as follows:

ANALYSIS OF SAMPLE NO. 2401.

	Per Cent.
Silica	75.27
Alumina	17.29
Iron oxide	0.83
Calcium oxide	0.46
Magnesia	0.18
Potassium oxide	0.32
Sodium oxide	trace
Loss on ignition	5.75

Two feet below this layer there is found a fine-grained, plastic clay, No. 2402, which would give a cream-colored ware. It would be well adapted for ornamental pottery having a colored glaze. This clay used with transparent glaze would give a cream-colored ware. The analysis is as follows:

ANALYSIS OF SAMPLE No. 2402.

	Per Cent.
Silica	65.70
Alumina	22.07
Iron oxide	1.33
Calcium oxide	0.23
Magnesia	0.36
Loss on ignition	6.90

Three feet below this layer is another one, No. 2403, which is well adapted for white earthenware uses. It is a good, plastic clay and gives a strong white body. An unwashed sample gave the following analysis:

ANALYSIS OF SAMPLE No. 2403.

	Per Cent.
Silica	65.03
Alumina	23.16
Iron oxide	1.00
Calcium oxide	0.29
Magnesia oxide	0.44
Loss on ignition	7.21

This is an excellent clay and it is very similar in composition to the sample of clay already alluded to, taken from one of the large Trenton potteries after it had been cleaned and mixed and tempered ready to be formed into dishes. The analysis is given on page 236.

By comparing this analysis with the last mentioned clay from North Dakota or with several others from North Dakota, it will be seen that it shows a marked similarity in composition. The North Dakota clay is a little higher in iron but it must be remembered that the sample from Trenton had been washed and prepared for ware, while the sample from North Dakota was just as dug. There is but little doubt that this clay is well suited for white tableware and other uses.

In the buttes about ten miles northeast of Dickinson there are several clays which from their physical tests appear to be fit for various grades of pottery. They are described as samples No.

2602, 2604, 2608 and 2610. Some of the clays found near Hebron, when properly mixed and treated, are apparently well fitted for certain grades of pottery. As examples, Nos. 2904 and 2905, the analysis of the latter of which is given below:

ANALYSIS OF SAMPLE NO. 2905.

	Per Cent.
Silica	73.90
Alumina	16.49
Iron oxide	1.25
Calcium oxide	0.29
Magnesium oxide	0.46
Potassium oxide	1.20
Sodium oxide	0.22
Loss on ignition	5.52

In the White Buttes about nine miles northeast of Dickinson there is a layer of dark, hard clay which might be used in the manufacture of earthenware. The analysis is as follows:

ANALYSIS OF SAMPLE NO. 2607.

	Per Cent.
Silica	70.27
Alumina	20.81
Iron oxide	0.33
Calcium oxide	0.23
Magnesium oxide	0.26
Loss on ignition	6.38

At the same place there is found a layer of several feet of very uniform white sandy clay, No. 2608, in which the clay could probably be separated from the sand so as to give a good white earthenware clay. The following is the analysis:

ANALYSIS OF SAMPLE NO. 2608.

	Per Cent.
Silica	75.65
Alumina	17.85
Iron oxide	0.49
Calcium oxide	0.23
Magnesia	0.18
Potassium oxide	0.88
Sodium oxide	trace
Loss on ignition	5.31

A very similar clay to the one last mentioned is found about thirty miles southwest of Gladstone. Sample No. 2103 gives the following:

ANALYSIS OF SAMPLE No. 2103.

	Per Cent.
Silica	76.24
Alumina	15.39
Iron oxide	0.79
Calcium oxide	0.34
Magnesia	0.33
Loss on ignition	5.12

In the Yellow Buttes about twenty miles southwest of Dickinson, about two feet below the top, there is a layer of several feet of light gray clay of the following composition:

ANALYSIS OF CLAY FROM YELLOW BUTTE.

	Per Cent.
Silica	63.64
Alumina	24.17
Iron oxide	0.95
Calcium oxide	0 45
Magnesia	0.98
Loss on ignition	7.60

This clay could no doubt be used for white earthenware.

For the purposes of comparison, analyses are here given of a number of earthenware clays found in different parts of the world and extensively used for various kinds of white earthenware. The clays which are low in silica in this list are usually mixed with clays higher in silica or with flint, or flint and other clay or feldspar.

The following table of analyses will show the composition of a number of china and earthenware clays from different localities:

ANALYSIS OF CHINA AND EARTHENWARE CLAYS.

CONSTITUENTS	New Jersey ware clay	New Jersey ware clay	Clay used in a Trenton pottery.	China clay, Cornwall, Eng.	Dorsetshire clay, used in Staffordshire potteries.	Impure or unrefined Cornishstone clay.	Porcelain, Berlin.
	No. 1.	No. 2	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
Silica	45.45	43.40	69.03	66.20	46.38	35.65	66.60
Alumina	38.75	37.56	23.89	24.11	38.04	32.50	28.00
Iron	1.15	1.04	0.45	0.79	1.04	1.65	0.70
Calcium	.....	.....	0.29	.....	1.20		0.30
Magnesia	0.11	.....	0.05	.....	trace		0.60
Potassium	0.17	0.35	.....	0.96			3.40
Sodium	.....	0.37	.....	.....		30.05	
Water and volatile matter	13.05	15.40	7.46	7.20	13.44		
Other matter	1.32	1.40	.....	0.20			

By comparing these analyses with the analyses of the clays of North Dakota which are given it will be seen that the samples from this state compare very favorably, taking all things into consideration. Moreover the large number of tests already mentioned which have been made at the School of Mines and those which have been made in a number of eastern potteries, indicate clearly that these clays are well adapted for the manufacture of earthenware and similar grades of pottery. With such valuable deposits of clay there would seem to be a future for the pottery industry in North Dakota. The demand for such wares is gradually increasing and there is little doubt but that sooner or later these deposits will be successfully developed. The clay industry in its various phases has grown to enormous proportions.

The value of the clay products of this country alone now aggregate probably one hundred and twenty-five millions of dollars or more annually. These deposits are located at considerable distances from any large pottery centers and as the population of the state increases these deposits of fine clays will be brought into closer proximity to a large supporting territory. The presence of coal near these clay beds will doubtless be of great help in their manufacture.

Although the results of these investigations are very encouraging it is not to be expected that a great industry like this demanding the expenditure of large sums of money and the employment of skilled workmen will be quickly developed. It is hoped, however, that the value of these clay resources will be appreciated and that in time the clays of North Dakota will be developed and their products extensively used.

PART V

METHODS OF BRICK MANUFACTURE AND DESCRIPTION OF THE NORTH DAKOTA INDUSTRY

BY

C. H. CLAPP

METHODS OF BRICK MANUFACTURE AND DESCRIPTION OF THE NORTH DAKOTA INDUSTRY.

BY C. H. CLAPP.

CONTENTS.

CHAPTER XI.

THE MINING OF CLAY.

PROSPECTING AND EXPLORATION.

To properly estimate the value of any clay deposit, one must bear in mind certain regulations as regards prospecting and sampling. North Dakota is especially rich in clay, and lately there has been a very considerable interest in the industry. Samples of clay are continually being sent in to the School of Mines, located at the State University, where such testing is done in its experimental and testing department. If the sample does not represent an accurate or fair average of the clay deposit, the examination is not of any great value. The amount of clay present in any one deposit, the facilities of transportation, the market for the goods manufactured, and other related conditions must be considered. Brick plants have been established without any preliminary propecting, and some of them are using inferior clays with poor transportation facilities, when higher grade clays exist in the neighborhood.

This section is introduced that the reader may be familiar with the methods of prospecting and sampling of clay deposits. The presence of clay is indicated in several ways. The most obvious is by means of an outcrop. Wherever there is a good section of the material underlying the surface loam such an exposure is called an outcrop. Sections are found where streams have cut into their banks, especially on the outside of any bends, or in buttes whose bare sides furnish excellent opportunities for a study of the material comprising them, or where any artificial cuts, such as wells, railroad or wagon roads, have been made. These outcrops are apt to be covered up again by the material washed down from above Also, the true nature of a clay bed may be obscured in this manner, as it may be stained or partly covered by other impurer material. Therefore the fresher the cut, and the more perpendicular, the better and the more reliable is the exposure. Clay suitable for brick is to be looked for in any broad flat area, especially where such an area is surrounded by hills. It is to be sought in the lowlands rather than in the highlands, as clay is washed from the highlands to the low. Many of the springs in the western part of

the state occur where a clay bed, underlying a porous stratum (usually coal) outcrops at the surface. The clay forms an impervious layer which forms the bottom of an underground waterway. The fertility of a district often indicates the nature of the subsoil, or material underlying the surface loam. The Red River Valley throughout its entire extent is underlain by clay. This holds the water in the overlying soil and makes it one of the most fertile regions in the world, but it also hinders the underground drainage of the district so that in wet seasons there is difficulty in farming, the soil being too wet and sticky.

The sampling of the clay deposit thus found is the next important step. We must first determine the amount of clay present. The extent and thickness of the bed may be obtained by an examination of all the other outcrops, by wells, cuts and borings. Borings may be made with a large auger. These augers are two to four inches in diameter, with a stem eight to ten feet long. This is an excellent means of prospecting where the clay is firm, but where it is wet and sandy the holes fill in as fast as they are formed, and in such cases a pipe must be used to line the hole, being pushed down as the hole is opened by the auger. In locating the extent of the bed, its character and structure should be noted. It should then be sampled and the clay tested either in a laboratory or by an established plant. In sampling great care should be exercised to get a sample which represents an average of the whole bed. A piece should not be picked out at random, but a little clay should be taken at regular intervals in vertical and horizontal directions, and these small samples all mixed together and after having been thoroughly mixed may be reduced in bulk if necessary. The greater the number of samples taken, and the greater the number of final samples tested, the more accurrate and the more valuable the results will be. In fact, clay testing, to be of any great value, should be made from samples gathered carefully and systematically.

The value of the deposit can then only be determined after a consideration of the adaptability of the clay bed for practical working. The clay may have a certain value, but if it costs more to get it into a salable condition than the price of the product, it is of course, as a business proposition, worthless. The ease and expense of mining the clay is an important factor. This is dependent on the amount of overburden and its character, and whether or not it has any use, the character of the clay itself, the necessity of drainage, and the method of mining employed. The transporta-

tion facilities must be considered, both for the raw clay and the finished product. The marketing of the product is a very necessary condition of success and is often a difficult proposition. It is thus seen that the character, extent, location and general adaptability of any clay bed must be carefully investigated before its true value can be estimated.

METHODS OF MINING.

The method of mining used for any particular deposit depends upon the character of the clay and other conditions, such as the amount of overburden and the facilities for drainage. When the bed lies near the surface, or is exposed by some section, and where the overburden can be easily removed, some method of surface mining is employed. Surface working is most common, and all the clay mined in North Dakota, without exception, is obtained in this way.

Open Pits.—Most of the clays used for common brick and fireproofing are obtained from shallow open pits. They are apt to occur in rather thin beds, immediately below the surface loam. Such clay beds are worked most economically and hence are used for common brick even when higher grade clays are available. The surface loam is first removed, unless this is of such a character that it does not interfere with the working of the clay. The material thus removed should be taken care of, so that it need not be rehandled in the further development of the deposit. The top soil having been removed, the clay is dug down to the bottommost limit of the bed, if shallow. If the face of the clay thus exposed is only a few feet (three to six) it is usually worked as a whole. The clay is picked down and then shovelled into carts or wheelbarrows, which are backed up against the face. When the clay is shovelled into carts, the bed is often worked in two or more benches for convenience in shovelling. A set of men begin digging at the top and work down a certain distance (two or three feet,) and work back along this level until they have reached the limit beyond which they can no longer conveniently load the clay into the cart. Digging is then commenced on the lower bench, and it is continued until the upper bench can again be worked conveniently. Sometimes two sets of men can be worked together, one on the upper bench, and another on the lower, the upper being a little in the advance. In this way the carts are loaded more quickly, and therefore more economically. Also, by this method of mining the

drainage of the pits is simplified. The ground water and rainfall may be collected in a sump, when it can be removed by pumping, or may be drained off into a ditch or stream. This is the method employed in working all the shallow beds of brick clay in North Dakota. (See Plate XV.)

Where such deposits are worked on a large scale, as in the extensive brick factories of some of the more populous states, steam shovels are used to dig the clay; and where large quantities are handled this is by far the most economical method. The working of the deposit is often carried on, and hastened, by undermining. The clay is dug away from the base of the face and then wedges are driven at the surface, one or two feet from the edge, and large quantities, often several tons, are thus forced off, which break up in falling.

The advantages of working in open pits with a comparatively low face are numerous. In this manner large quantities of clay may be dug, the face being worked in differnt places without any interference. There is no attempt made to hold the face up, as the wash is small. The clay is well exposed to the weather, and dries rapidly, facilitating the digging. The ground water can be easily drained off. In rainy weather, however, large amounts of clay are wet and difficulty may be encountered in draining off the excess of water from broad, shallow pits. Where the overburden is thick much stripping is of course necessary; but where only the surface loam is removed this stripping is not expensive. Since the mining of the clay for the manufacture of cheap wares must be carried on most cheaply, this is the most advantageous method.

Quarrying.—When a bedded shale or clay is mined, especially those not adapted to digging with a pick or shovel, some sort of quarrying method is resorted to. Except in hard shales, of which there are none in North Dakota, the methods are not exactly those employed in a stone quarry, but rather modifications of them. These bedded clays are usually worked on the outcrop.

If the entire bank is clay no stripping is necessary; more often however, a greater or less thickness of overburden must be removed, and this is scraped off to one side. If the clay is to be used for the more ordinary purposes, and the overburden is free from boulders or harmful constituents, it is allowed to fall down and become mixed with the rest of the bank. Thus, in the manufacture of brick, for example, in the brick plant at Kenmare often the whole bank, although it may contain several grades of clay and

Clay pits at the Hunter yard at Grand Forks, showing the method employed in mining the valley clays.

even more or less fine sand, is mined and mixed together. For a higher grade product, however, care must be taken to keep the different materials separate, and any mixing that is done is in definite proportions. In cases, therefore, where the bank is made up of different layers, they are usually worked at different levels.

The method of working such deposits is to pick in under the bank, and then by a series of charges placed in nearly vertical holes along the top of the face, to shoot down large quantities of clay. At the Mayo plant the face is undermined by a tool built like a breaking plow, but with a narrow blade. The clay and shale thus broken down may be shovelled into carts or cars and hauled to the plant, or may be conveniently removed and carried short distances by scrapers, as is done at Burlington.

In some cases it is better, however, to leave the material thus broken down for a time to the action of the atmosphere, that is, allow it to weather. Weathering breaks up hard indurated clays and softens them by disintegration or slaking, and by leaching out certain soluble constituents that served as a cementing material. A weathered clay is more plastic than the unweathered clay. Certain soluble salts which might produce a coating or efflorescence on the burned ware are removed to a great extent. Other insoluble impurities may be changed to a soluble condition by weathering, and thus gotten rid of. Therefore, weathering is recognized as being most beneficial to most clays and especially shales, and in many cases large quantities are broken down and allowed to weather for a long time, especially over winter, before being used. The Benton shales, exposed in the Pembina Mountains, are notably improved by weathering.

The advantages of this kind of mining are easily seen. Large quantities of clay can be easily removed and exposed to the weather. The plant also can be situated at the bottom of the exposure, and the clay run in by gravity, thus greatly reducing the cost of transportation of the clay.

Underground Mining.—Underground methods of mining of clay are costly and are seldom resorted to. It is only permissable where the clay is high grade and not obtainable near the surface, and where the overburden is large and underground mining is cheaper than any form of surface mining would be. This method is costly because of the necessity of timbering, and is especially expensive is clay mines because of the tendency of the material to give way. Lighting and ventilating are also expensive as well as

the drainage, for pumping is usually necessary except in the case of drift mining, where the clay slopes toward its mouth and the water may be made to run down and out.

The output of underground workings is also restricted. Underground mining can be carried on from drifts or shafts. Where a tunnel or drift can be driven in along the clay bed from the outcrop, this is usually done, but if this is impossible, it is necessary to reach the bed by a shaft. The actual systems employed are liked those used in mining coal. The two common methods are the room and pillar system, where the vein is thick and the roof poor; and the longwall system where the vein is thin and the roof good.

Underground mining of clay is only practiced at the Washburn Company's plant at Wilton, where it is carried on in connection with the mining of coal. Here the clay underlies the coal bed, and as the mine was already equipped with shaft, hoisting machinery and so forth, the method employed was thought to be the cheapest. The clay is undercut with electric undercutting machines and then blasted down. The room and pillar system is used. Except under peculiar conditions, however, underground mining cannot compete with surface mining because of the added cost.

Haulage.—Clay dug from open pits and used for common brick is usually carried to the plant in wheelbarrows or carts. In such cases the plant should be located near the pits. It is impossible to economically handle large amounts of clay, or to carry it for more than a few yards by means of wheelbarrows. Where the clay is soft enough, wheeled scrapers are very efficient in moving large quantities of clay for short distances. For longer distances, two-wheeled dump carts are used. This is most economical in transporting clay for a distance of a hundred to three or four hundred yards, where the slope is gentle or nearly level. For these distances only two to four carts are necessary to supply an ordinary machine producing 40,000 to 50,000 brick a day. The horses soon learn to follow the beaten paths to and from the pits, and a boy can take care of all the wagons and horses. When the distance is increased the number of carts must also be increased, and the cost of keeping the roads in repair must be considered, for if the road is allowed to become worn the extra wear on the carts and horses becomes expensive.

Therefore, for long hauls it is best to build tracks from the pit to the plant, and to haul the clay in cars. Horse haulage over a

tramway is much more economical than over common roads, as a horse can pull more clay in cars than in carts, and also the horse need not be kept waiting for the loading and dumping of the cars, but can be hitched immediately from a full car to an empty one at the plant, and after pulling the empty one back to the pit may again be transferred directly to a full one. When the distance is over 1,000 feet, and a locomotive can be kept constantly employed, it is cheaper than horse haulage. A steam tram, the only one in the state, is to be completed this year at the Hebron plant, where the clay pits are five miles from the plant.

Cars used for hauling clay are like the ordinary mine cars. They are built of wood or steel, and may be end, side or bottom dumping. This last type of car may be made automatic in its action by placing a projecting rod on the track which releases a clutch holding the doors of the car shut. The cars hold from one to three cubic yards of clay. Large quantities of clay can thus be transported easily, and handled, especially dumped, conveniently.

When the bottom of the clay pit is several feet lower than the plant, so that the grade from the pit to the preparing machinery is steep, the clay is best hauled into the plant by cars, which are operated by a cable. The cable is wound on a drum situated at the works, and the car is thus drawn up. This is probably the most economical method for elevating clay for long distances and is employed when necessary in this state. Where the clay mined is above the plant, it may be transported to the works by a gravity tram. In this method the loaded car pulls the empty car back to the pits by means of a cable attached to a winding drum, one end of which unwinds as the loaded car descends, thus furnishing the power to haul up the empty car attached to the other end of the cable. It is also sometimes possible to dump the clay direct from the pit onto a tipple, which slides the clay down to the works. Clay may be slid down a steep hill to the plant for short distances with but little trouble, on the hill itself the clay being helped along by scrapers if necessary, as is done at the Mayo brick plant.

These last methods are very inexpensive, and if possible the plant should be built below the clay deposit and the clay moved downhill throughout the process. If any elevation of the clay is necessary, it is cheapest to elevate it high enough at the start so that it is not necessary to again lift it during the process of manufacture, as the cost of rehandling of the clay is thus saved. Of

course, it is desirable to have the plant and pits near together, but other things must be taken into consideration. It must be born in mind that for moderate distances it is cheaper to transport the raw material than the finished products, when the transportation has to be done on roads or ordinary trams. In this state particularly, it is best to build the plant where railroad facilities are the best, for the cost of transporting the finished product to the various markets is one of the greatest considerations.

Fig. 1. Mandan Brick Plant, showing man molding bricks by hand.

Fig. 2. Fargo Brick Plant, showing horse power brick machines and method of open-yard drying.

CHAPTER XII.

THE MANUFACTURE OF BRICK.

PREPARATION OF THE CLAY.

Clay as it is mined is seldom in a condition to be used directly in the manufacture of ware. It is usually more or less lumpy, and may even be hard, as is the case where a shale or flint clay is used. It is necessary that the clay be ground to a fine condition in order that it may be properly tempered, and thus capable of being moulded. The finer the grinding the greater the plasticity which is developed. As it comes from the pits the clay is seldom uniform in character, and to be burned successfully it is necessary that the ware be made of homogeneous material. If such is not the case the product will be of different sizes, owing to differences in shrinkage, of different colors and of a general miscellaneous character. It is very important, therefore, that the clay be brought to as uniform a condition as possible before it goes to the moulding machinery. This is accomplished by reducing it to a fine condition and thoroughly mixing. The more a clay is washed before being molded, the more uniform the product will be. This preparation of the clay is accomplished by two general methods, the dry and the wet.

Weathering.—Weathering is sometimes resorted to in order to reduce a clay to a fine condition, or to get rid of soluble constituents, or to decompose harmful minerals, such as pyrite. The clay is spread out over some flat surface, two or three feet thick, and is exposed to the weather. The alternate wetting and drying caused by the rain, wind and sun, and in winter the frost action, breaks up the material to a fairly fine condition. Weathering is particularly adapted to shales. It is not a complete method in itself, the preparation being continued, usually in the wet way.

DRY METHOD.

Crushers.—When a hard shale or flint clay is to be ground it is best to first reduce it to pieces of one-half inch to two inches in diameter in some form of jaw crusher. There are two main types of such crushers, the Blake and Gates. The Blake type consists

of two jaws, one of which is stationary and the other movable. These jaws are set so as to form a V-shaped opening, the bottom of the opening being adjusted to the size of crushed material desired. The movable jaw works on a pivot, and is moved back and forth by means of an eccentric, thus crushing the material. Plate XVI shows two views of this style of crusher. This type has a capacity of twelve to eighteen tons, requiring fifteen to eighteen horse power. The Gates mill has a cylindrical hopper inside of which revolves, with a gyratory motion, a cone-shaped head with corrugated surfaces. This type has a larger capacity than the Blake, but is not so convenient if the plant is worked in small units. When the clay is hard, one of these crushers reduces it to a convenient size for the dry pan or other pulverizer, and saves these machines a great deal of wear.

Rolls.—Crushing rolls are used extensively in grinding clay. They consist of two rolls revolving in opposite directions, the clay passing between them. The size of the ground clay is regulated by the width of the space between the rolls. They have the advantage of reducing the clay to fine particles of a uniform size and of breaking up pebbles and lumps in stony clays. Large lumps should not be fed to them, but should be first broken up by some form of crusher. The clay should be dry, as when damp it tends to merely flatten out into a ribbon. There are several types of machines, each particularly adapted to a certain kind of clay.

In the ordinary type both rolls are of the same diameter and smooth. This is adapted to material of a uniform character. For lump clays, the best type is one in which one of the rolls is larger than the other, the larger one drawing the lumps between the rolls, and the smaller one disintegrating them. Many machines have projections on one or both of the rolls, such as short teeth, bars, corrugations, or threaded grooves. These rolls are adapted to tough, sticky and stony clays, as the projections help to draw the clay through the machine. Conical rolls and threaded rolls are used where the clay contains large stones, which are removed automatically. The stones which are too large to pass through are carried with conical rolls to the larger end and discharged through a chute. The elimination is more effective in threaded rolls, the stones being carried along by the grooves until the end of the roll is reached. Two types are shown in Plates XVII and XVIII. A set of ordinary rolls has a capacity of 2,500 to 10,000 brick per

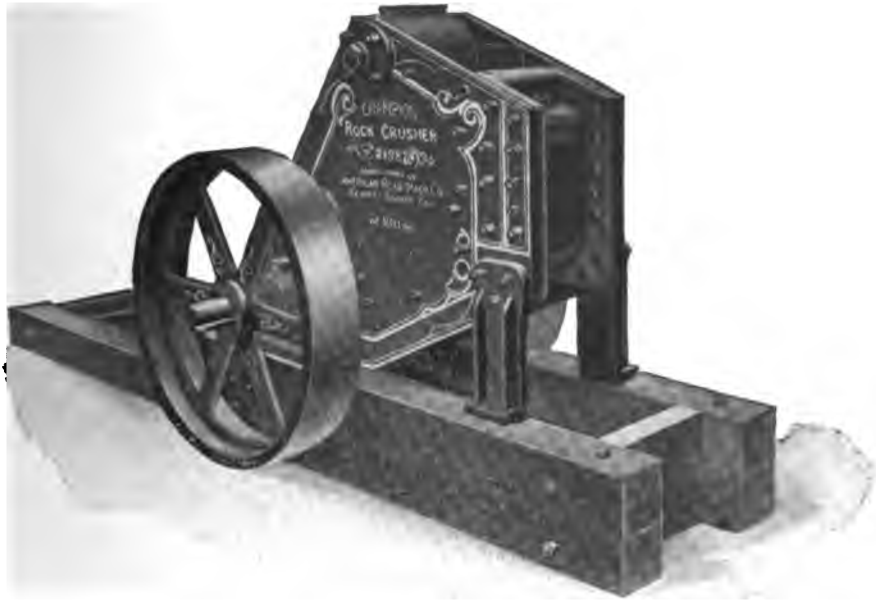


Fig. 1. Clay crusher.

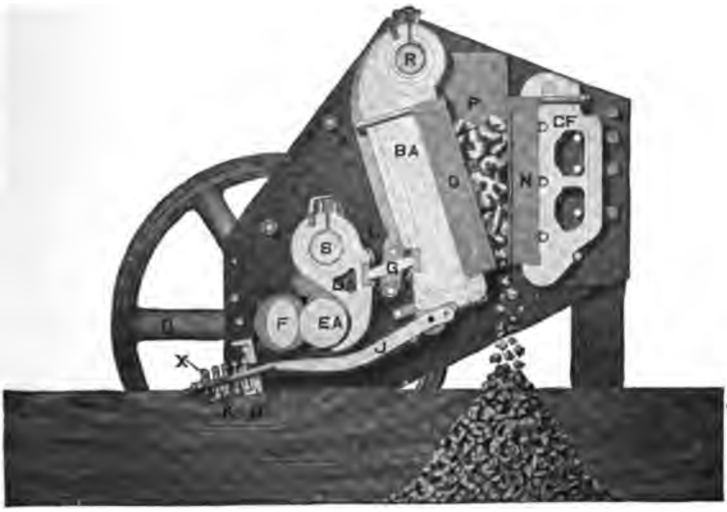
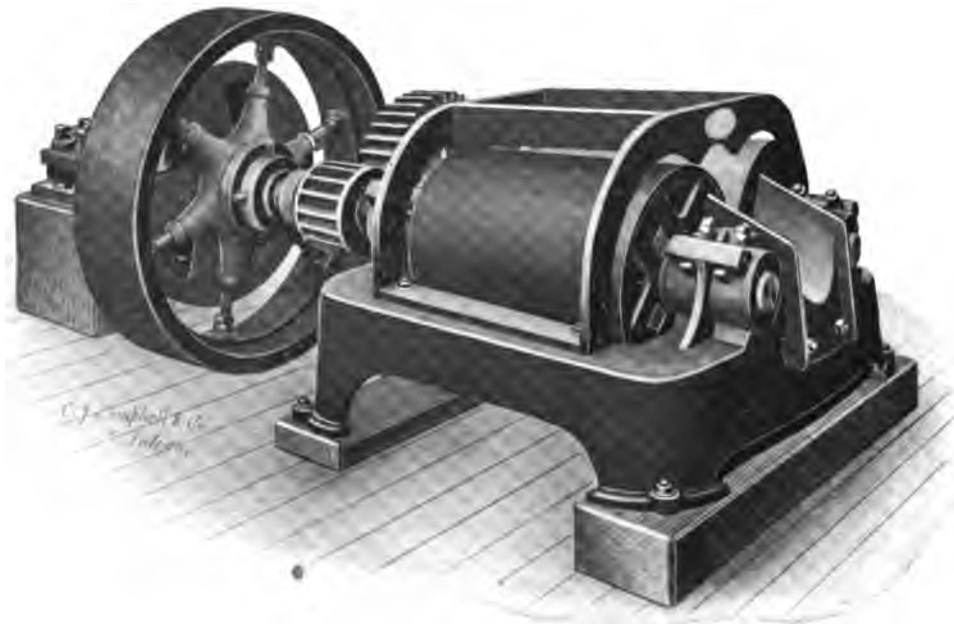
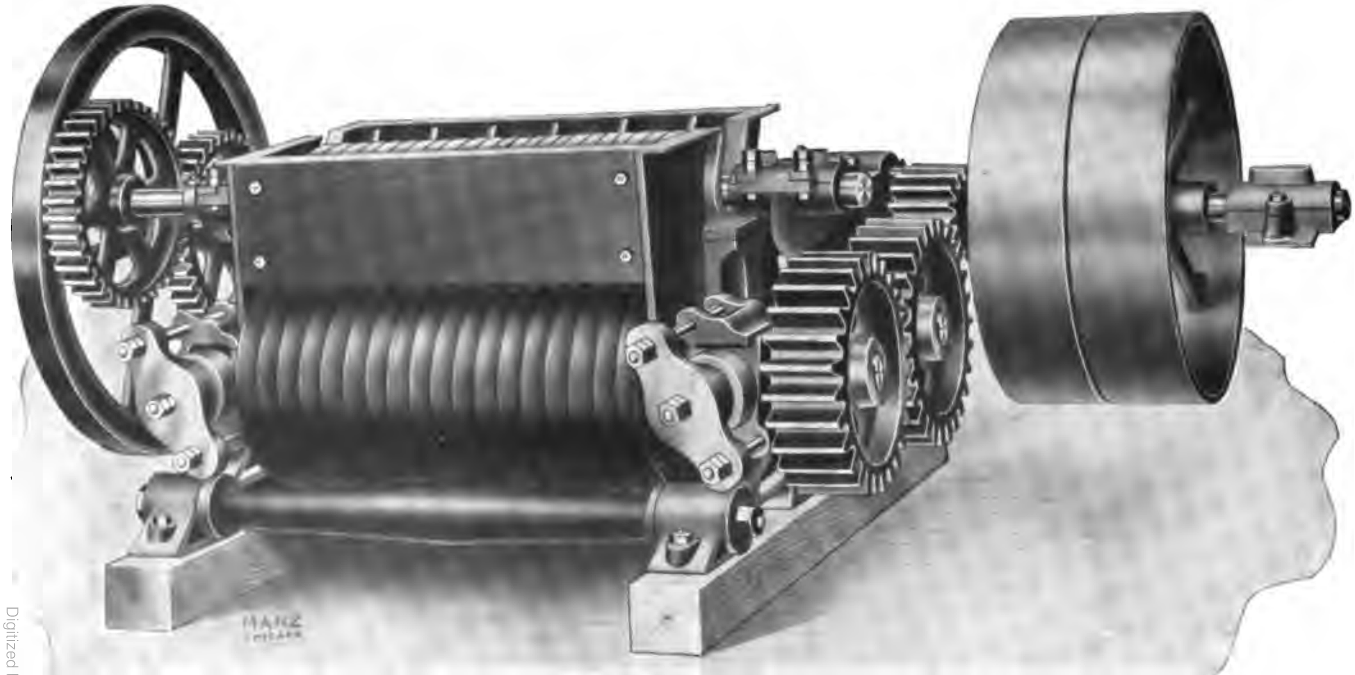


Fig. 2. Sectional view of clay crusher.



Conical roll crusher.



Corrugated roll crusher.

hour, depending on the speed at which the rolls are run, from 150 to 300 revolutions per minute, and the character of the clay.

Disintegraters.—Disintegraters are special types of grinding machinery, the product from which is completely pulverized. They are of two types, those which pulverize by rubbing, and those which pulverize by impact. The former are represented by the special forms of rolls already considered; the latter by two well known types, the Steadman Disintegrater and the Williams Pulverizer. The Steadman machine consists of four cages of round bars, revolving one within another and in opposite directions. The clay is fed in at the center and is carried outward by the centrifugal force. At is passes through the several cages the lumps are broken by the impact of the bars of the cage, and by striking against each other. The fineness to which the clay is ground is regulated by the speed of the machine, which runs from 400 to 600 revolutions per minute.

The Williams mill is the same in principal. It consists of a series of hammers attached to a rapidly revolving shaft. The hammers are pivoted at one end and swing outward by centrifugal force. The clay is fed in at the top or side by means of a hopper, and disintegrated by the impact of the hammers.

These machines have a large capacity, but require a large amount of power. Their capacity runs from 60 to 400 tons per day and requires from ten to forty horse power. They are used to best advantage dry, crushing clay for the dry press process. They are not good for very hard or very soft materials, but are excellent for clay shales. They are good mixers, and hence can be employed advantageously where two or more kinds of clay are used together.

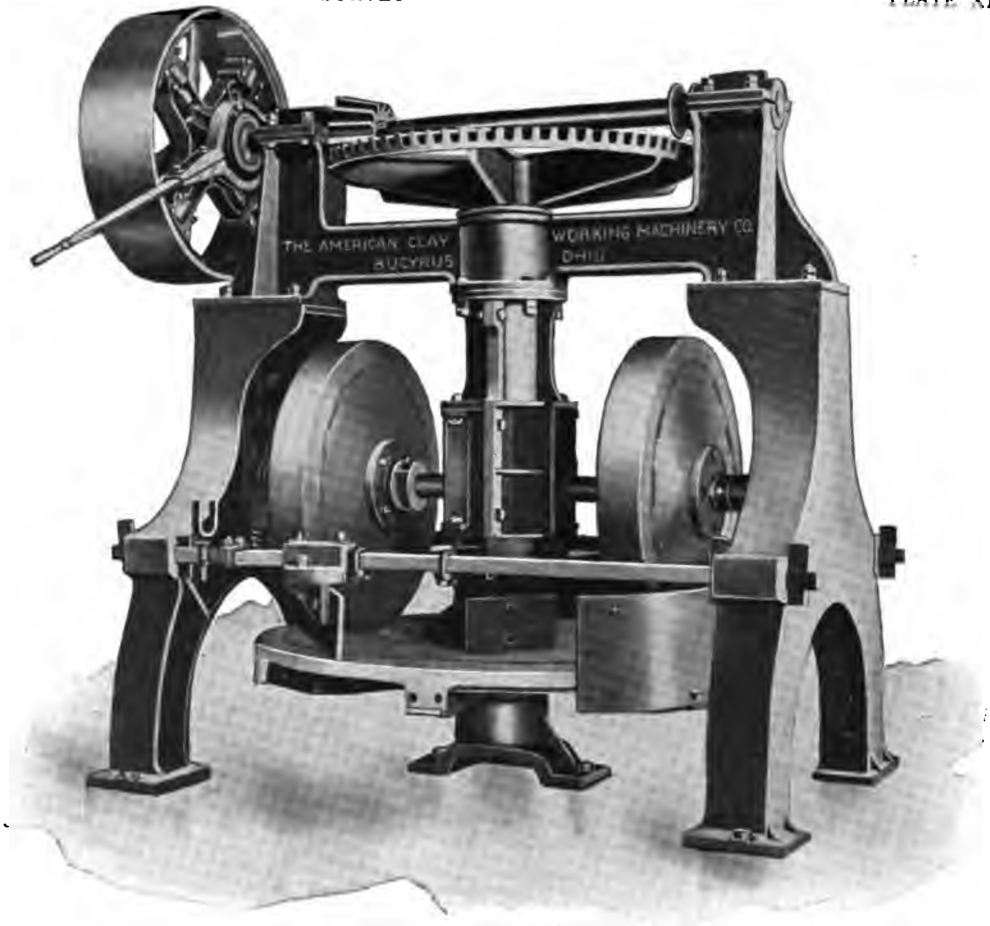
Dry Pans.—The dry pan is extensively used, more than any other type of machine, for crushing shale and hard, tough clays. It consists of a circular pan in which revolves two large, heavy mullers form one to four tons in weight. These mullers are supported on a horizontal axis, they are best independent of each other, and are set in motion by the revolution of the pan, but do not travel around the pan. The clay is crushed by these rollers by means of their great weight. The material is pushed in front of them by scrapers, and is pulverized until fine enough to pass through the screen plates, forming the outer part of the pan. The clay is thrown outward by the centrifugal force and if not crushed fine enough to go through the screen, is returned by the scrapers under

the mullers. Below the pan the fine clay collects and drops into the boot of a bucket elevator. This carries it to a screen, the oversize from which is returned to the pan and reground.

Dry pans are supported by heavy, strong frames of wood or steel. The wooden frames are more or less elastic and take some of the strain from the machine, but they are clumsy and are apt to work loose and throw the pan out of line, causing extra wear. The steel frames are rigid, and more expensive than the wood frames, but last longer and are more economical in the end. Power is transmitted to the pan by means of a cog wheel pinion, best situated at the top of the frame in order to be kept as free of dust as possible. The muller shafts are usually independent of each other and are supported by heavy springs so that they can move up and down to allow for the large and small lumps of clay as they pass under the rollers. If the mullers were on one continuous shaft, the raising of one would effect the other, which is of course undesirable, because of the excessive strain and wear. The springs holding these shafts in places are adjusted so that the rollers can be set as close to the grinding plate as is desired. To allow for wear the rims of the rollers are chilled iron, and are replacable. The grinding plate is solid near the center where the mullers run over it. The screens which are perforated plates, form the periphery of the pan. The size of the mesh varies from one-eighth to one-quarter of an inch. The entire weight of the revolving pan, mullers and shafts is supported by the step underneath. This is a very important point, and great care is taken to prevent excessive wear. It usually consists of some form of plate bearing of anti-friction metal, and immersed in oil.

The size of the dry pan ranges from five to nine feet in diameter. Its capacity is larger than that of any other type of machine, but the clay should be dry in order to pass through the screen plates without clogging. For a nine foot pan, the capacity would be about 100 tons a day through one-eighth inch mesh, requiring from twelve to sixteen horse power. (Plate XIX.)

Screens.—For satisfactory dry crushing it is necessary to screen the end product in order to get a material of uniform grade. The clay from the dry pan or disintegrater is collected in the boot of an elevator and thence carried to the screen. Two types of elevators are in use. For carrying clay up slight inclines belt conveyors are used; for raising clay up vertically or steep inclines, bucket elevators are employed.



Dry pan.

Clay screens are included under three general types, inclined, stationary, shaking and rotary screens. The first is the most common type and consists of a screen ten to fifteen feet long, inclined at an angle of 30 degrees to 45 degrees. The mesh is either made of heavy wire or perforated metal. The latter is much better, as the wear is less and it is easier to keep clean. The clay is fed from the elevator to the top of the screen and falls down over it by gravity. The steeper the angle of the screen the finer the screenings will be. These screenings are caught in a chute underneath, and are carried to the moulding machinery. The oversize is delivered at the bottom of the screen to another chute which returns it to the crusher, where it is reduced to a finer condition. These screens are cheap and easy to keep clean, but their capacity is limited.

This fact has led to the introduction of shaking and rotary screens. The shaking type is inclined at a low angle, and swings by chains or springs so that it can be shaken back and forth by some reciprocating motion usually obtained by an eccentric. The vibration may be either longitudinal or transverse, the latter motion being preferable. These are shorter and take up less space than the stationary screens and while their capacity is much larger they are more expensive.

Rotary screens are cylindrical or polygonal in shape. The mesh is suported by frames of iron and steel. The whole is inclined at a slight angle and revolved on a longitudinal axis. The polygonal screens, which have from four to twelve sides, are more efficient than cylindrical. A special improved type of revolving screen is one where the screen plates are made to move, by means of sprocket wheels at each end, over a long inclined framework. The clay is fed in at the top, and the screen plates move upwards against the flow of the clay. This retards the flow and the screening is most thorough. Revolving screens are the most efficient and require the least space, but are more expenisve, and more difficult to keep clean.

WET METHOD.

If a clay is to be moulded by any plastic method it must be worked up with water in order to make it plastic. This process is called tempering. Sometimes with soft clays it is possible to grind and temper a clay in the same operation. However, most of the tempering processes are mixing rather than grinding in their action.

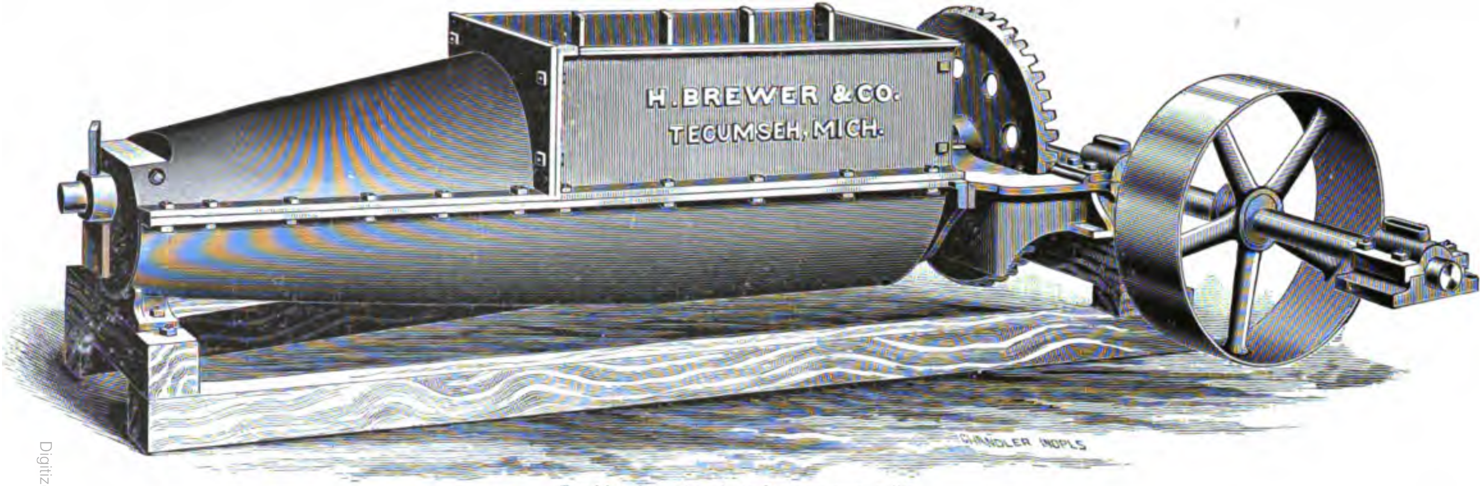
Wet Pan.—The best type of machine for crushing and tempering at the same time is the wet pan. This resembles the dry pan in construction but the mullers are narrower, and the bottom of the pan is solid. The clay and necessary amount of water is fed into the pan, and allowed to remain until the clay has been thoroughly ground and tempered. By means of plows and scrapers the clay is continually mixed and thrown under the rollers. When one charge is finished it is removed by a shovel pivoted near the pan, and another charge introduced. This is accomplished without stopping the pan, but of course the work is intermittent, as one charge must be removed before another is added.

A wet pan is well adapted to working up soft, plastic clays, which are more or less lumpy in their character, or contain pyrite or limonite, for the stiff-mud process. They are used extensively in stoneware and sewer-pipe factories.

Soak Pits.—Soak pits are used at many of the common brick yards where the soft mud process is employed. A hole is dug into the ground, three to five feet deep and eight to ten feet in diameter, either circular or rectangular, and lined with planking. The clay or clay mixture is dumped into the pit and mixed with water, and allowed to stand over night, during which time the material becomes thoroughly softened. The pit is usually built next to the brick machine, and the clay is shovelled directly from it into the pug mill of the machine. It is customary to have two soak pits for one brick machine, one pit being filled, while the other is emptied. This avoids the necessity of having two machines. The soak pit does not mix the clay, it require considerable space, and a large amount of labor. Its only advantage is its cheapness. Plate XX.

Ring Pits.—Ring pits are an improvement over the ordinary soak pits, because the clay is not only tempered, but mixed. The pit is built like the ordinary soak pit, circular in form, about twenty feet in diameter, three feet deep and lined with boards or bricks The clay is stirred by a large, heavy iron wheel, six feet in diameter and weighing about 600 pounds, which revolves around the pit, and is geared by a rack and pinion to travel from the center of the pit to the outside. The rim of the wheel is usually in two sections which increases its cutting and mixing power. The wheel sometimes is operated by steam, but more often by horse power. The whole charge, containing clay enough for a day's run of 20,000 to 30,000 brick, is mixed at one time and requires four or five hours.

Anderson Brick Company's yard at Fargo, showing soak pits.



Combination closed and open pug mill.

Two pits are usually employed for one brick machine. Although these pits are much better than the ordinary soak pits, they have less capacity and require more space and labor than pug mills.

Pug Mills.—Pug mills are almost universally used to temper clay for wet or stiff mud machines. They consist of a semi-cylindrical trough, ordinarily six to twelve feet long, although they are made up to sixteen feet in length, and two to four feet in diameter. In this trough revolves a shaft carrying knife blades, which are set at an angle to the perpendicular, and arranged spirally around the shaft. The clay and water is fed in at one end and is pushed by the revolving blades to the other and discharged. At the same time the clay is broken and cut up by the knife-blades and becomes mixed and tempered.

The trough is made of wood or steel, steel being preferable. Mills are made with open and closed top, but the open top is desirable, as the operator can watch the process and determine better the amount of water that is needed. The closed top machines are worked under pressure and capacity and efficiency are greater. Plate XXI shows a combined closed and open machine. Pug mills with two shafts are manufactured, the shafts revolving in opposite directions and the blades interlocking, thus greatly increasing the effectiveness, and making it possible to use even stony clays directly. The thoroughness of the tempering and mixing depends on the rate at which the clay passes through the mill, which is proportional to the length of the machine, the rate of revolution of the shafts, and the angle at which the blades are set on the shaft. Some clays necessarily need to be tempered longer than others. Ordinarily a pug mill will prepare clay enough for 30,000 to 50,000 brick in ten hours.

The pug mill is satisfactory, since it tempers and mixes thoroughly with a small expenditure of power and limited space. A fairly soft clay may be charged directly into one, but a hard or stony clay should be prepared by some form of crusher or pulverizer, the dry pan and the pug mill often being employed together. Pug mills are sometimes combined directly with the brick machine, but as these mills are short, the clay is best tempered before it goes into them.

MOLDING.

Bricks are manufactured by three processes, namely, the wet or soft mud, the stiff mud and the dry press.

Soft Mud.—In the soft mud process the clay is tempered with a large amount of water, so that the mixture is very soft and easily molded. In this condition it is forced into wooden molds which are sanded in order to prevent the wet clay from sticking to the sides. The excess of clay is scraped off even with the top of the mold by a wire or knife blade, and the bricks dumped on the drying floor, or on pallets. The soft mud brick have therefore five even sanded surfaces and one rough surface from which the excess of clay was "struck" off.

Soft mud bricks are molded either by hand or by machine In the hand made brick the clay is tempered to the right consistency, softer than for machine molding, in a pug mill. The molder takes a lump of clay, more than enough to fill the mold, and throws and presses it into the mold box. The clay should be soft enough to fill the whole mold completely. Four or six molds are made in each form, and after they are all full, the brick maker strikes off the excess of clay even with the top, by means of a wire or thin blade. The off-bearer then takes the filled molds to the drying yards and dumps them out to dry, or turns them out onto pallets, which are placed on the floor of an open yard or in racks. When the molder does nothing but mold the bricks, he can turn out 5,000 or over per day. The hand made brick is more porous than the machine molded. The capacity is limited, and the method is restricted to small yards, with a limited, intermittent output.

If brick is to be made except on a very small scale, it is therefore much more economical to use a brick machine. These machines are operated either by animal or steam power. The clay is fed into the machine, where it is mixed by a short pug mill, and finally forced into the press box by two wide blades. It is then pressed into the molds by a plunger of some sort, the filled molds being pushed forward automatically onto the delivery table. Here the excess of clay is struck off by a thin, broad knife blade, and the brick form is passed on to the off-bearer. After the filled molds, six bricks being usually molded at one time, are pushed forward, an empty frame of molds takes its place in the press box, being pushed in from behind, where the sanded molds are inserted into the machine.

These soft mud machines are of two types, vertical and horizontal. In the vertical machine, the pug mill consists of a short vertical box in which a vertical shaft, carrying the blades, rotates. The clay moves to the bottom more by the force of gravity than by the action of the knives. The press box is in the front of the machine, and the clay is forced into the molds by a vertically moving plunger, by swinging press plates, or by a horizontally moving plunger which forces the clay against an inclined plate forming the front of the press box, and is thence directed downwards through the dies into the mold. In the other type of machine, the pug mill is horizontal and longer and the clay is pushed directly from the pug mill into the press box. The molds, which are placed in the machine at the rear of the press box so that two sets of molds are in the machine all the time, should be properly sanded with sharp, clean sand to prevent the clay from sticking to the sides of the mold. This sanding may be done by hand, but is done faster and more economically by an automatic sander. This consists of a framework, on which the mold boxes are fastened, revolving in a cylinder, in the bottom of which is placed the sand. The molds are filled with sand at the bottom and as they are brought up on the opposite side they are reversed and the excess of sand drops out. The sander is so regulated that the molds are sanded just as fast as they are used by the brick machine.

The Martin machine is fitted with an automatic striker, the excess of clay being removed as the mold is pushed forward.

The capacity of a soft mud machine, run by ten to twenty-five horse power, varies from 35,000 to 50,000 brick per day. Those operated by two horses with a sweep almost twenty feet long, have a capacity of 20,000 brick. They require a man to feed and temper the clay, a man to strike off the molds, another to tend to the sanding and feed the molds, a man to dump the bricks onto the pallets, two to five men (depending on the number of brick made per day) to place the pallets in the drying racks or on the drying floor, and also a couple of boys to wash molds, and to bring the empty pallets to the machine.

The soft mud process is adapted to a large variety of clays ranging from very plastic to lean ones. Those with a high shrinkage can be grogged heavily and used when they could not be worked by the stiff mud process. Some clays may be fed directly to the machine, but most of them have to be first tempered in a pug mill or soak pit. The resulting brick is uniform in texture and usually

quite porous. They are not affected very much by frost action, as the pores are so large. The surfaces of the brick are rough and the edges apt to be rounded and broken, which is not desired in a front brick, although such a brick, if it has a good color, is now very popular in the large eastern cities. The brick may be made denser, with smooth, sharp edged faces, by repressing when partly dried. The capacity of a wet mud machine is low and the labor great compared to a stiff mud machine. The soft mud process is extensively used, and when a brick of uniform texture is desired, without laminations, as is the case with fire brick, this process is almost universally employed. (Plate XXIII.)

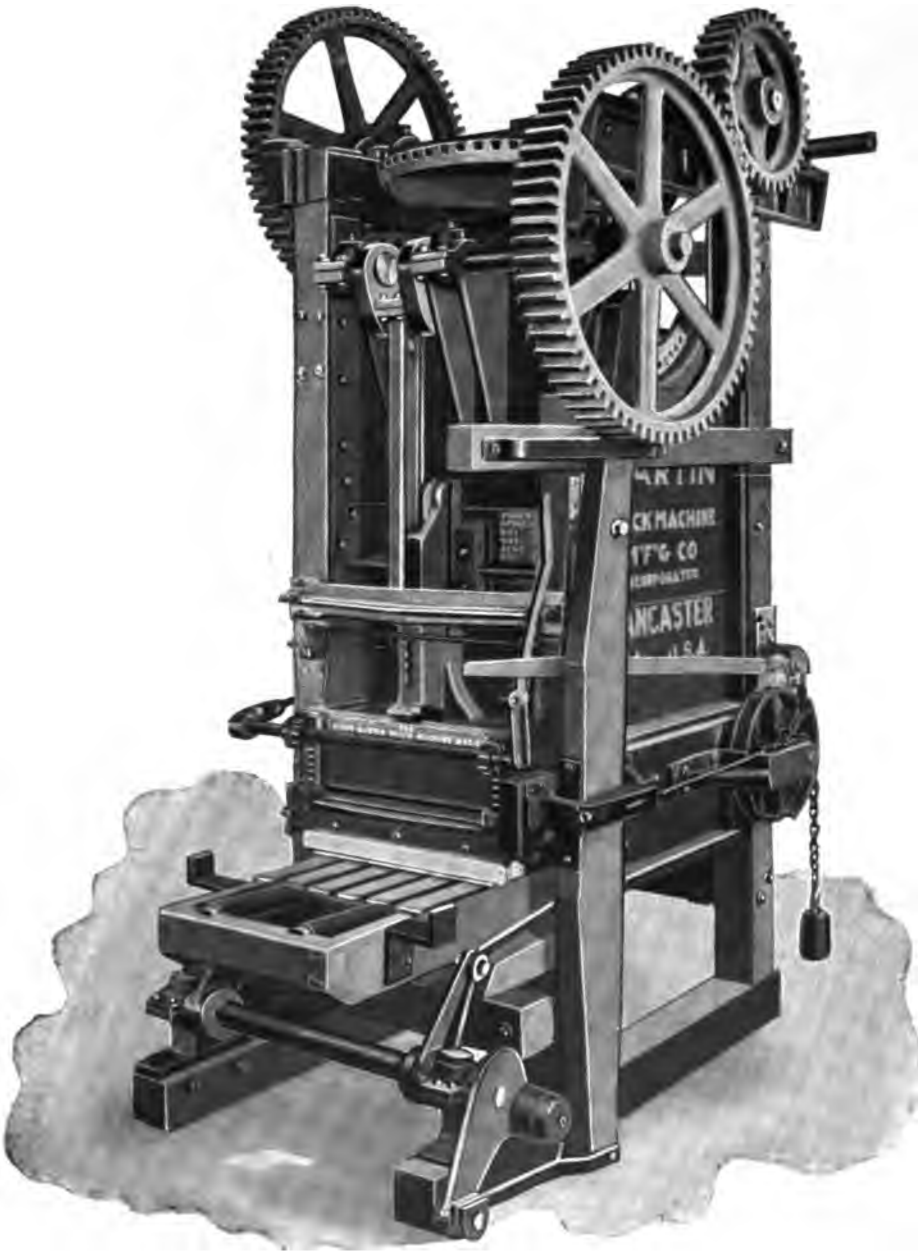
Stiff Mud.—In the stiff mud process the clay is tempered with much less water than in the soft mud. It is still in a plastic condition, but stiff and capable of holding its shape after being molded, even when subjected to some strain. It requires considerable pressure to mold the clay in this condition. This pressure is furnished by an auger (the plunger type of machine having nearly disappeared), which forces the clay out of a rectangualr opening or die. The clay issues as a continuous bar, and is pushed out over a cutting table, where the bar is cut into bricks by wires.

The stiff mud machine consists of a vertical or horizontal cylinder (the horizontal type is preferable and used most extensively) which is closed at one end and tapers at the other to a rectangular die. In this cylinder revolves a shaft which at the closed end carries a few tempering blades, thus forming a short pug mill. At the other end is a large auger. Sometimes a pug mill and auger are combined in a single machine.

The clay is fed in at the closed end of the machine. It should be well tempered beforehand. A great deal of trouble is experienced if the short pug mill of the machine is left to finish the tempering. The clay is mixed by a few knife blades and is forecd along to the auger. Here it is pushed forward rapidly and powerfully until it issues from the die in a continuous bar.

The dies are of various sizes and designs. If the brick are to be "side-cut" the cross section of the die is the same as the length and width of the brick; if "end-cut," the same as the width and thickness. With end-cut brick the die is often made double or even triple, two and three bars of clay issuing from the machine at the same time. Ries[1] states that that is undesirable. In order to reduce the friction between the clay bar and the die, which

[1] New Jersey Geol. Survey, Vol. VI, p. 229.



Soft-mud brick machine.

tends to produce a laminated structure, as will be described later, and also to tear the sides of the bar, they are very carefully designed. They are steam heated, or lubricated with water or oil. Sanders are also attached to the best machines and sand the surface of the bar as it issues from the die. This prevents the clay from sticking to the belt which conveys the bar to the cutting table. and the bricks from sticking to each other. It is also said that this helps to give the brick a better color when burned.

One undesirable feature of stiff mud machines is the resulting lamination in the brick. This structure is caused by the auger and die. When the clay is seized by the screw of the auger, it is pulled out and twisted around the shaft. It is also polished by moving over the smooth surfaces of the screw, and these polished surfaces do not adhere well when the clay is pushed out through the die. As the bar leaves the machine, the center, not being held back by the friction of the die, moves faster than the sides. From these causes the bar of clay becomes more or less laminated, either parallel to the length, or width, of the bar, or possibly both. On drying and burning the concentric layers tend to shrink away from each other, increasing the lamination of the brick. These laminations are most pronounced in very plastic clays, or in those which have been tempered with too much water. They may be eliminated to some extent by working the clay stiffer, by having it properly prepared before it is fed into the machine, and by keeping the supply constant. Some machines are also doubtless better than others, those with insufficient pressure and a short cylinder being most objectionable. By repressing properly the laminated structure may be destroyed and the brick more firmly bound together. However, the laminations do not seem to effect the strength of the brick as much as might be supposed.

The bar of clay is carried from the machine by means of a conveyer belt to the cutting table. Here it is cut up into brick by means of fine wires, which are drawn through the clay. Cutters are operated either by hand or are automatic, the latter being commonly used. They are of two general types, oscillating and rotary, there being three or four kinds of rotary cutters. The oscillating cutter consists of a number of parallel wires fastened to a framework, the distance between them representing the thickness of the brick. This framework is pushed laterally across the clay bar, either by hand or automatically. The wires thus drawn through the clay cut it up into separate bricks, from four to seventeen

being cut at one time. In the old cutters it was necessary to stop the brick machine while the wires were being drawn through the clay, but now the cutter is carried forward with the bar of clay and at the same rate, returning to its original position after cutting, thus insuring that the brick are cut at a perfect right angle. A cutting table of this type is shown in Plate XXIV. This type of cutter is used for side-cut brick.

Rotary cutters may have their axis of rotation either parallel or perpendicular to the clay column. In the former, the wires are placed radially and cut the brick in a manner similar to that of the oscillatory table, the cutter being carried forward with the bar of clay while it is operating. One of these is pictured in Plate XXV.

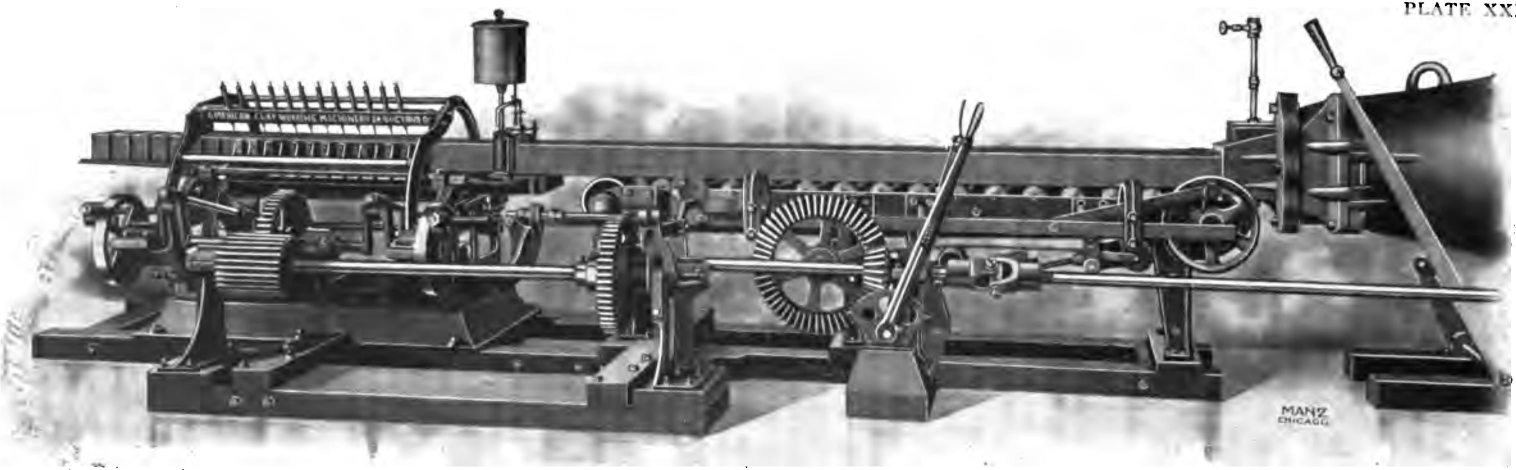
In the other type of rotary cutter, the wires are carried on fork-like frames arranged like the spokes of a wheel. As the cutter moves the wires cut the clay column into bricks. The velocity of the circumference of the wheel is the same as the bar of clay so that the brick are cut perfectly square. This type is shown in Plate XXVI.

Both of these types of rotary cutters are used for end-cut and side-cut bricks.

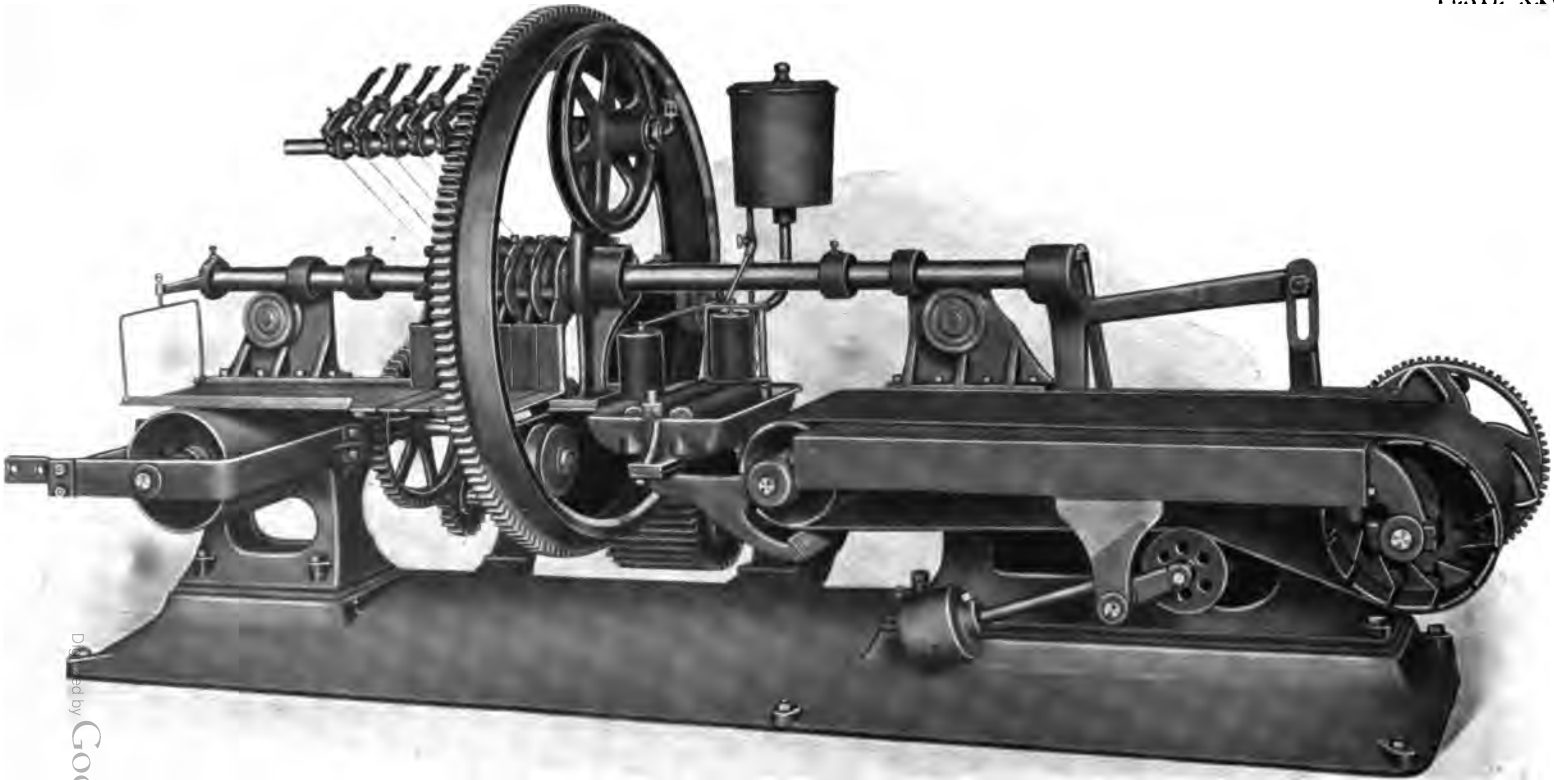
The wires used for cutting must be strong, so as not to be easily broken, yet small enough to keep the friction low and make a smooth cut. Considerable trouble is experienced with the wires breaking, especially in stony clays. Various devices have been invented to adjust the wires to any degree of tension by means of regulating screws or springs, and also so that they may be quickly replaced without stopping the machine.

The cutting plate on which the clay moves is kept polished in order to reduce the friction. The column is also lubricated plentifully with oil to prevent sticking by guide rollers which are kept wet with oil from a reservoir above the table. As the brick are cut they may be taken off at one side on a pallet, either automatically or by hand, or more often, with automatic cutters, they are pushed onto another belt conveyor, which moves at a higher rate of speed than the cutting table. This separates the brick, so that they can be easily picked off and loaded on cars, or placed in the repress.

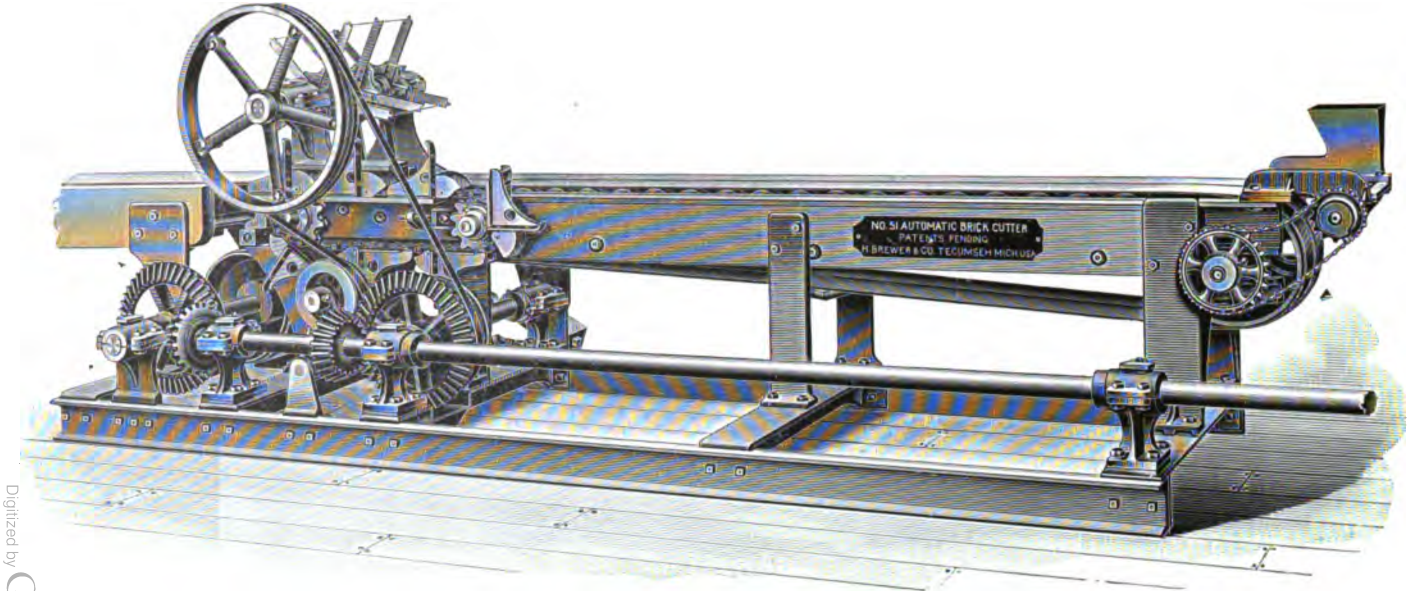
This process is preferable because of its great capacity, good machines having an output of from 50,000 to 100,000 per day, with 50 to 75 horse power. The labor required is much smaller than in the soft mud process, the drying takes less time and the resulting brick are stronger. Clays of moderate plasticity and low shrink-



Automatic oscillatory reciprocal side-cut table.



Rotary automatic cutter.



Automatic brick cutter.

age are best adapted to the process. Stony clays cause much trouble by breaking the cutting wires, and every clay should always be thoroughly prepared before entering the machine, in order to avoid stoppages, which, although they may be short, are expensive. The advantage of this method is its larger output, and everything should be done to keep this as large as possible.

Repressing.—Bricks manufactured by both the soft and stiff mud processes are repressed in order to give the brick smoother surfaces and sharp edges for front brick, or to imprint on them some design or trade mark, or to make them stronger and denser for use as paving brick. Repress machines, which may be operated either by hand or power, consist essentially of a steel mold box in which the brick are placed and subjected to a high pressure by means of a movable plunger. In the hand machine, in which one brick is molded at a time, it is placed in the mold box, and the pressure applied by means of a long lever, which pushes the plunger, forming the bottom of the mold, upward. The pressure is relieved by moving the lever back; the bottom plunger is thereby still further raised so that the brick is level with the top of the mold, whence it is removed. After the plunger has been dropped into place again, another brick is put in the mold and the operation is repeated. The capacity of these machines is from 2,500 to 3,000 per day.

In the power machines the bricks are fed automatically from the off-bearing belt into the molds. Two bricks are usually pressed at one time. The pressure is applied by means of toggle joint or crank and acts from both the top and bottom of the mold. Two maximum pressures are given with a partial relief between, pressures of about 45,000 pounds to the square inch being used. With the relief of pressure the bottom of the mold box is raised, and the brick pushed forward automatically to an off-bearing belt. A power machine has a capacity of about 25,000 per day and requires from one to two horse power. The molds must be oiled liberally to prevent the brick from sticking. Stiff mud bricks can be repressed directly after molding, but soft mud bricks must be partially dried, during six to twelve hours.

The appearance of the brick is greatly improved by repressing. The faces are rendered smooth and are somewhat polished by means of the oil and friction; also, any desired shape may be given the brick, or any design stamped upon it. This has been the popular method of making front and ornamental brick, but is now replaced very considerably by the dry press process.

It has also been supposed that repressing always improves the strength and wearing qualities of paving brick. It gives a smooth, dense surface, but it may or may not increase the wearing qualities. This fact was brought out by a series of tests, carried on by the National Brick Manufacturers Association. The results of their experiments were given out as follows:[1]

"Makers of paving brick should assume that their plain wire-cut brick are superior to the repressed brick until they have proven by careful comparison under identical tests, that the assumption does not hold good in their case.

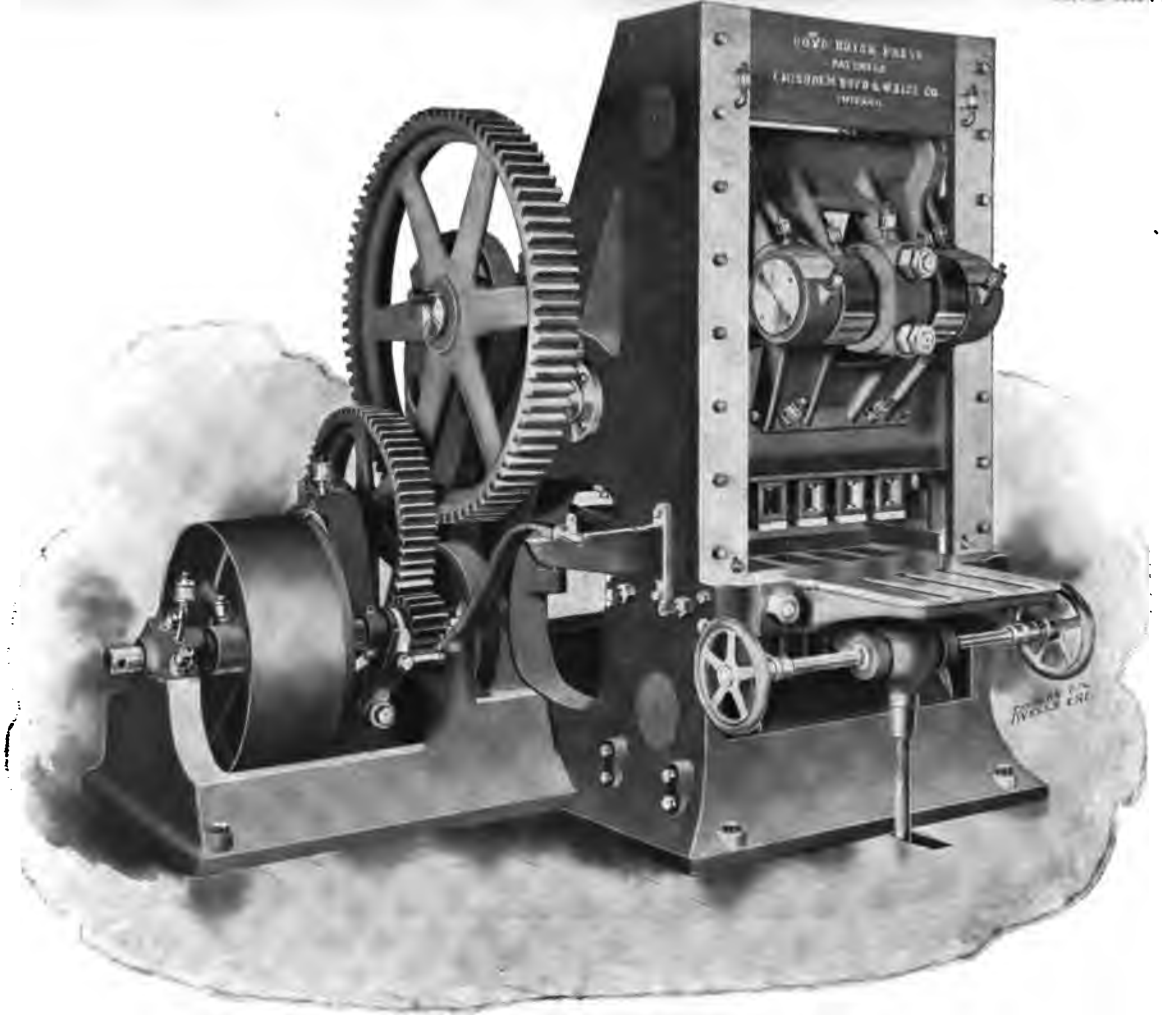
"If repressing is necessary to meet market conditions, the maker should perform the operation so as to cause a radical breaking up of the auger machine structure, and the production of a new and characteristic structure due to repressing. If this is done, the probabilities are that no falling off in quality will occur and actual gain in strength may frequently result."

The probable reason of the falling off in strength which ordinarily occurs is that the molded brick fits rather loosely in the repress mold, and when repressed, the auger structure is broken down, but no new one is given to the brick, and so the bond is weakened. If, however, an entirely new structure is given, as recommended, the brick fitting very loosely in the molds, this more than compensates for the loss of the old.

Dry Press.—In the dry press process, the clay is molded in a nearly dry condition, containing from 5 to 15 per cent of moisture; enough so that the clay partly holds together when pressed together in the hand. The clay is first stored for some weeks in large sheds, "sweated," as it is called, in order to allow the moisture to become evenly distributed, and for the sake of general uniformity. It is then ground so that it will pass through a twelve or fifteen mesh screen, and stored in a hopper above the brick machine, to which it passes by means of a canvas tube.

The press (Plate XXVII) is a massive machine of great strength. A steel frame carries the plungers, which are operated by means of toggle-joints or cams, the mold boxes, feed boxes and delivery table. The clay is pushed forward by a charger, which carries just clay enough from the feed box to fill each mold, two to six bricks being molded together. Pressure is then exerted by means of the plungers acting from above, the bottom of the mold also rising slightly. The bottom plungers are then raised, and carry the bricks

[1] Report N. B. M. A. Committee on Technical Investigation, p. 92. Quoted in Iowa Geol. Survey, Vol. XIV, p. 239.



Brick dry press.

to the level of the delivery table, onto which they are pushed by the charger, which advances to refill the molds. The pressed brick are removed and placed on carts and sent directly to the kiln.

In some the pressure is applied gradually, but in the best machines two or even three distinct pressures are given. This allows the inclosed air to escape more freely from the holes which are left in the die plates for that purpose. If the air could not escape the compressed air would break the brick after the pressure was relieved.. The pressure is sometimes exerted by hydraulic rams, but the toggle-joint type of machine is preferred. Pressures as high as four tons per square inch are used. The molds are heated by steam in order to prevent the clay sticking to the die plates. These die plates may be made of different shapes, and ornamental brick of all descriptions may be manufactured. The capacity of a four mold dry-press is 20,000 bricks per day, of a six mold press, 30,000. The capacity is thus not large and the plant is expensive but as the brick go directly to the kiln, the great expense of drying is eliminated. The brick are not only strong and durable, but are smooth and sharp-edged, and are good facing brick. Bricks of various designs and shapes can be made without repressing, and the method is undoubtedly the best and cheapest for the production of a high grade brick.

DRYING.

Bricks or other ware, made by the soft or stiff mud process must be dried before they can be placed in the kiln. Water exists in clays in three forms; as water of combination, hygroscopic water and tempering water, or water of plasticity. Water of combination is, of course, only eliminated at high temperatures. Hygroscopic water, the moisture absorbed by all porous substances from the atmosphere, is driven off at the boiling point of water. It is not necessary that this should be removed before placing the brick in the kiln, and it would be useless, as the green brick would only reabsorb moisture from the atmosphere while the kiln was being set. The water required to temper the clay, which varies from 15 to 35 per cent, must on the other hand, be eliminated before the brick are placed in the kiln, for if it were not it would be impossible to set the brick more than ten or twelve courses high, they would be injured more or less in the handling, and in the burning the water would be given off too quickly and unevenly, so as to check and crack the brick very badly.

Air is the medium employed to carry away the water vapor given off from the drying clay. The evaporation goes on more rapidly the higher the temperature of the air, because of the fact that the air has more power to absorb water at higher temperatures than at lower, also because it takes less energy to change the water into vapor. Air at a definite temperature can only hold just so much vapor, and therefore the drier the air to begin with the more efficient the evaporation will be. The more air used, and the greater velocity, the more rapidly the drying takes place.

An immense amount of water has to be evaporated from a tunnel drier full of brick, and when drying is done in closed chambers the efficiency of the method influences the economy of the production very much. In a tunnel containing twelve cars each loaded with 500 standard brick, five tons[1] of water must be evaporated, usually in 24 hours. The problem thus becomes of great importance to obtain the greatest evaporation with the smallest amount of heat, always bearing in mind that the chief consideration is to dry the ware without injurying its shape or strength.

Drying is carried on in (1) open yards, (2) covered yards or pallet racks, (3) on drying floors, or (4) in tunnel driers which may be intermittent or (5) continuous.

Open Yards. Open yards are used to some extent for drying soft mud brick. The brick after they have been molded are taken to the drying yard and dumped out of the mold directly onto the floor of the yard. The floors are of earth, which has been rolled hard and smooth, or of brick. The brick are dumped in long rows. and are allowed to lay flat for a day or more and are then turned up on edge by a rake-like arrangement consisting of a board fastened perpendicularly to a long handle, and allowed to dry for about a day longer. They are then piled up several courses high in hacks and allowed to dry for three to five days. These hacks are provided with covering boards to protect the brick from rain. (See Plate XXII.)

In this method the bricks are dried entirely by the sun and wind, the equipment being almost nothing and therefore the method is inexpensive. It is, however, entirely dependent upon the weather. Although the hacks are somewhat protected, the brick laid out on the floor are ruined by a heavy rain. A yard with a clay floor is all tracked up by the workmen, and the brick stick to it if wet, and it has to be rerolled and smoothed which takes a long time.

[1] Iowa Geol. Survey, Vol. XIV, p. 239.

Fig. 1. Richardton Brick Plant.

Fig. 2. Plant of the Grand Forks Brick and Tile Company.

This difficulty may be removed by drying the brick on boards or pallets which are placed on the floor. On bright sunny or windy days, the drying goes on very fast, and the brick are apt to check badly by the rapid shrinkage. The method is of course restricted to warm weather as the tempering water would freeze in cold. The labor required to operate an open yard is large compared to its capacity. They require a large amount of space, and the percentage of brick lost in drying is great, so that this method is going out of use, and where open air drying is desired this older method is being replaced by covered yards, the brick being dried on pallet racks.

Covered Yards. The system of drying in covered shed on pallet racks is very popular in this state. The brick as soon as they come from the machine are dumped onto a pallet. These pallets are best made of slabs of wood, or of iron or steel, so the brick may dry through the bottom as well as on the top and side. The pallets are carried from the machine to the racks by hand, carts or conveyors. The racks are upright posts with horizontal arms to hold the pallet boards, ten or twelve courses in each rack, and each row of racks, which are as long as convenient, is covered by a gable roof the sides of which extend over the brick and protect them from the sun and rain. Space wide enough to permit proper handling of the brick is left between each row of racks. (Plate XXVIII.)

The roof completely covers this space, or it may be covered by hinged roofs in rainy weather. The capacity of a set of these racks varies with the size of the plant; those in this state have a capacity of 100,000 to 350,00 brick, and are not too large for convenience

In this system the brick are dried more by the circulation of air than by the direct heat of the sun. One week is usually required for drying. The brick do not dry so rapidly at first as they do in the open yard and so the danger of checking is avoided to a great extent. The roof protects the bricks from injury during rainy weather. The method is, of course, restricted to warm weather the same as the open yard, and is influenced to a great extent by hinged roofs or movable canvas covers. The labor and space required is decreased, and in the automatic systems the economy of the method is still better. These advantages make the method a popular one for drying ordinary soft mud brick, and is used most extensively.

Floor Driers. Brick, especially fire-brick, and other ware, such as sewer pipe, fire-proofing and stoneware, are sometimes dried by means of hot floors. The floors are solid or slatted. The solid floors

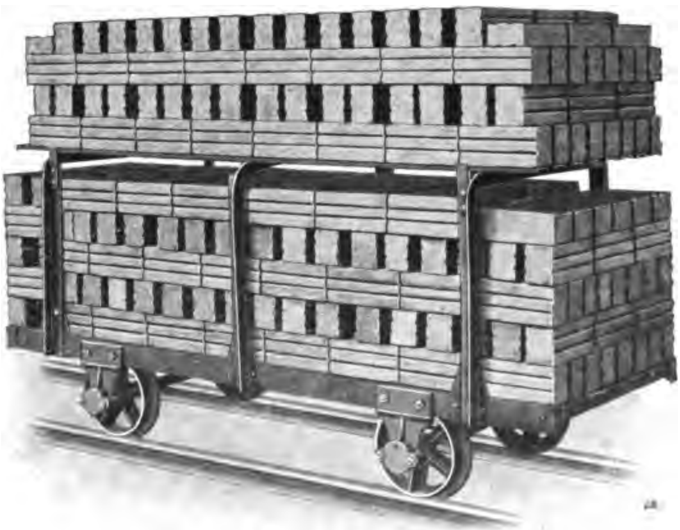
are built of brick or cement, and have a fireplace at one end with flues running underneath the floor connecting with a chimney at the other. The brick are placed on edge and the water vapor evaporated by the heat of the floors and the relatively cool air currents carry off the water vapor. The advantage of the floor drier is that it is cheap to build, but on the other hand fuel is burned for the sole purpose of drying. The distribution of the heat is poor and a great deal is lost by the escape of warm air, which is not near to its saturation point, and by radiation. A large amount of labor is also necessary, so it is a rather expensive method. Grimsley[1] gives the cost of drying in one plant using this method with gas fuel as 33 cents per thousand brick. There are not many clays which are susceptible to this process of drying, for the uneven heat, the bottom of the brick next to the floor being at a temperature around 212 degrees F., and the top being relatively cool, causes the brick to crack and warp. The method is used chiefly for the drying of fire brick which are porous and refractory and may be dried rapidly, without affecting their strength.

Slatted floors are used in drying sewer pipe, stoneware, and other hollow ware. The floors are built of common lumber with spaces to the width of one to one and one-half inches between them. They are heated by steam pipes which run just below them. Three or more floors are used together, one above the other, corresponding to the working floors of the factory. During the working hours the exhaust steam is used for heating, but during the night full pressure steam is employed. No direct currents of air exist save those produced by the ordinary ventilation of the factory. It is thus possible to dry ware that is very tender.

This system is wasteful of heat and expensive to build, but nevertheless is it used most extensively when the ware must be dried carefully.

Periodic Tunnel Drier. Periodic or intermittent tunnel driers consist of a series of parallel tunnels built of brick. Each tunnel is supplied with its own heating and ventilating system, so that the drying in each one may be regulated independently of the others. The green brick are loaded on cars and pushed into the tunnel on tracks. With soft mud bricks the cars are provided with pallet racks. With stiff mud, however, the bricks may be piled up, either on single or double deck, several courses high. The capacity of these cars is from 300 to 600 brick. (Plate XXIX.)

[1] West Virginia Geol. Survey, Vol. III, p. 123.



Double deck car loaded with 530 bricks.

When the tunnel is filled the drying air is turned on, and so regulated that the brick are dried to the best advantage. Three stages of drying are noted by Professor Beyer:[1] (1) Heating; this consists in warming the brick gradually up to the temperature at which the evaporation is carried on. This is done in a moist atmosphere, so the brick will not dry too rapidly, and check. (2) Shrinking; in this stage most of the water is evaporated and the total amount of air shrinkage is accomplished. This is carried on as rapidly as the clay will stand, the temperature of the air being increased and the humidity decreased as the process nears the end. (3) Complete evaporation; in this last stage the water in the pores of the clay is eliminated, the temperature being raised nearly to the boiling point of water. The dried brick are then removed, and the tunnel is cooled down to receive another charge. Several tunnels are worked together, so that while one is being loaded another may be drying, while a third is being emptied and cooled down.

The drying air passes underneath the tunnel in a large flue and escapes through small openings along the whole length of the flue into the tunnel. The air is heated by steam coils or pipes, usually just before entering the drying chamber. The warm air passes up through the brick, absorbing moisture from them. The moisture-laden air is then drawn off through small openings by a number of small chimneys, communicating directly to the outside atmosphere, or by means of flues to one central larger stack. The amount of air entering the tunnel, its temperature, and the humidity of the outgoing air are thus under good control.

This control of the drying conditions is the chief advantage of this system, as it enables the clay to be dried without harm, so that it is possible to dry clays without checking, which are difficult to dry by any other method. On the other hand, it is wasteful of heat, the outgoing air not being near its saturation point, and large amounts also being wasted while the chambers are emptied and cooling. Owing to its intermittent action the capacity is also low, and when possible the continuous drier takes its place.

Continuous Tunnel Drier. The object of the continuous tunnel drier is to save fuel. In a large plant the expense of fuel is always great, and much pains are taken to save all the heat generated, thus keeping the consumption of fuel low. This method utilizes most all the heat with great economy, and also may employ the waste heat from cooling kilns or waste steam.

[1] Iowa Geol. Survey, Vol. XIV.

The construction of the continuous tunnel drier is much the same as the intermittent. The hot air is, however, only allowed to enter the tunnel at one end. It is drawn through the chamber, gradually absorbing moisture from the brick, and escapes laden with water vapor almost to its saturation point, through a stack at the other end. The brick from the molding machinery is loaded on cars, similar to those used in the periodic drier, and are introduced, one car at a time, into the tunnel at the stack end. Here they are warmed up by the hot, nearly saturated air, just before it escapes. As each new car is introduced into the tunnel the brick are pushel along towards the hot end. They thus gradually pass into a warmer atmosphere, which also grows less humid. At the extreme end the moisture is completely eliminated by the dry hot air as it enters the chamber. At this end the brick are removed and sent to the kiln. In this process the three stages of drying overlap each other somewhat.

The tunnel driers differ mainly in the manner in which they are heated. Beyer[1] classifies the different heating systems as follows:

Direct heat—By fuel burned for the purpose; by waste heat from other processes.

Indirect heat—Radiated from heated brick; radiated from steam heated surfaces.

In the first system a furnace is built at the hot end of the tunnel, the hot gases and products of combustion passing to flues underneath the tunnel, and from there into the drying chamber. In order to free the furnace gases from soot, they are first led to a brick chamber where the soot is settled out. The gases are then diluted to the right temperature by cold air drawn in from the outside. The mixing of hot and cold air, the draft and circulation are best controlled by a fan. The disadvantages of this method are that there is no saving of waste heat, and that there is danger to the drying ware from soot and acid scums. The soot may be eliminated by better combustion in the furnace, secured by mechanical stokers, and more draft. However, the acids which are formed by the combustion, notably sulphurous and sulphuric acids, may deposit as a dew on the brick at the stack end of the drier, if the out-going air is up to its saturation point, as sometimes happens. If any of the components of the clay are attacked by the acid, a scum is formed on the surface of the brick.

The heat from cooling kilns is successfully employed in larger plants to heat the driers. It is drawn into a chamber through a

[1] Iowa Geol. Survey, Vol. XIV, p. 255.

system of flues, and then mixed with air to the right temperature just before the hot air goes to the drying chamber. This circulation is best maintained by a fan, which permits of proper regulation of cooling air, and the amount forced into the tunnels. Attempts to use the direct products of combustion from the burning kilns have so far been a failure, due to sooting, scumming and improper regulation of temperature. The utilization of the waste heat from the cooling kilns is a great advantage, the heat necessary for drying being furnished cheaply. It is necessary, however, in plants of ordinary size to provide auxiliary furnaces to furnish heat where there is not enough to be had from the kilns, or in case of accident. Also, the kilns are cooled more quickly, in half the usual time, it is claimed, thus increasing the kiln capacity of the plant. The advantage of this method is therefore twofold.

In the Sharer drier, which is of the indirect heating type, furnaces at the discharge end of the drier furnish the heat. The gases of combustion pass through flues directly underlying the brick floor of the tunnels, and out of the stack at the entrance end. Air is drawn into the drying chamber by flues situated on each side of the furnaces, and is thus brought up to the required temperature. The air passes through the tunnel and out the same stack as the furnace gases, which arrangement furnishes a better draft in the drying chamber. The furnace gases also heat up the floor of the drier, which thus acts as a drying floor. As the brick are not placed on the floor they are not heated unevenly. This method is simple and does not require much fuel, but on the other hand it does not use any of the waste heat which is so plentiful around a brick plant. There seems to be no reason why the gases from the burning kilns could not be used to furnish the heat necessary, by means of regenerative chambers, such as are used in heating air for iron blast furnaces.

In the steam-heated tunnel pipes are laid underneath the track or along the sides. The steam for each tunnel may be regulated separately. At the discharge end the temperature is raised by extra steam coils. Waste steam is used during the running hours and live steam at night. It is possible that steam might be generated in the waste heat boiler, utilizing the combustion gases from a burning kiln. Steam driers are conveniently handled and the temperature regulated easily; there is no danger of fire, and waste energy may be employed.

For tender clays special driers are used to separate the stages of drying more definitely, and especially to prolong the first heating stage. The moist air is drawn off at the entrance end, under the track and entrance doors, or the stack is placed near the discharge end, and there is hence practically no air current near the entrance. With such driers very tender clays may be dried by this method.

Brick require from 24 to 48 hours to dry in one of these tunnels. The temperature at the entrance is about 100 degrees F. and at the hot end about boiling point, 212 degrees F. One to four tracks are laid in each tunnel. The capacity varies with the number of tracks and their length, but many have a capacity of from 150,000 to 200,000 brick.

The advantage of the continuous tunnel driers are their large capacity and great economy of fuel.

BURNING.

Changes in Burning. The changes which occur when a clay is burned are primarily of a chemical nature. However, these changes greatly affect the physical properties, for the comparatively weak, soft, unenduring, air-dried clay is changed into a hard, strong body. It is this property possessed by clay which makes it of value. The chemical reactions which take place in burning are of a similar nature in all clays, although the temperature at which like reactions take place varies considerably. These chemical reaction are accompanied by corresponding physical changes. The former have been conveniently classified by Orton[1] into three divisions, which represent different stages in the burning, each of which is more or less separate from the others. They are as follows: (1) Dehydration, (2) Oxidation, and (3) Vitrification.

Dehydration. In the first period the greater part of the volatile constituents is eliminated, and of these water is the chief. Water has been said to exist in clay in three forms, namely, tempering water, hygroscopic water, and water of combination. These three forms are each driven off at different temperatures. The tempering water is eliminated by drying, and there is none, or should be practically none, present when the ware is set in the kiln. The hygroscopic water is only completely driven off at boiling point. It is necessary that all this water should be removed before the ware is heated above 212 degrees F., otherwise steam would be formed which, collecting in the pores of the clay, might be unable to escape,

[1] On the Role Played by Iron in the Burning of Clays, Edward Orton, Jr., Brick, Vol XX, p. 33, Trans. Am. Ceramic Soc. Vol. V.

and expanding, break the clay. Therefore, the brick should be heated very slowly to the boiling point of water in order to eliminate the uncombined water, so as to prevent "popping."

During this period a large excess of air should always be present. Otherwise there is likely to be a condensation of the moisture from the overladen atmosphere as it escapes from the kiln. If there is considerable precipitation of water the bricks are likely to become soft and may lose their shape to some extent. Especially is this true in down-draft kilns, where the moisture-laden air escapes at the bottom and is likely to soften the bottom tiers, which must bear the weight of the whole column of brick. To eliminate this difficulty down-draft kilns are sometimes arranged so that they can be burned as up-draft kilns during the first stage.

Another difficulty met with in this period is the danger of scumming or whitewashing. Sulphur, if it is present free or in pyrite, is oxidized at a low temperature and combining with water forms sulphurous or sulphuric acid. These acids attack the soluble constituents of the clay, especially lime, and form salts which, when the moisture is evaporated, are deposited on the brick, forming a scum or wash. To prevent the danger of whitewashing or deforming the brick a good draft of air should always be supplied during this period.

After the elimination of the hygroscopic water at boiling point the clay, according to Beyer[1], may be brought rapidly to a low red heat, 1000 degrees F. or 550 degrees C., at which point the water of combination begins to be given off. This is the period of "water smoking" during which the combined water is eliminated. This period lasts through 270 degrees F. or 150 degrees C., and when a red heat has been reached the water should be entirely driven off. Pains must be taken during this period to prevent bloating, which may be due to confined steam or the action of the liberated water or other gaseous ingredients. The temperature should be raised very slowly through this stage.

During this period of hydration most of the carbonaceous matter in the clay is burned off. This usually causes little or no trouble, unless large amounts are present, when the temperature of the kiln may be raised excessively due to the burning of the hydrocarbons liberated and this may distort clay of low fusibility. A reducing atmosphere will be formed which prevents the formation of ferric oxide unless a large excess of air is present. A reducing atmosphere

[1] Iowa Geol. Survey, Vol. XIV, p. 275.

also hinders the liberation of the sulphur. Throughout the period, therefore, a good circulation of air is necessary, for the atmosphere must be an oxidizing one.

Oxidation. In the second stage, the period of oxidation, the iron is oxidized to the ferric state. The reactions, begun in the latter part of the first period, namely, the oxidation of the carbon and sulphur, is completed. These reactions should be entirely finished before the temperature is high enough to start the brick on the third stage, that of vitrification. If care is not taken that the brick be completely oxidized before vitrification is begun, the brick will be liable to lose its shape by the liberation of gases from the unoxidized interior, which being unable to escape through the vitrified surface, expand and bloat the brick. Therefore, the temperature should be raised slowly through this period (up to 900 degrees C. or 1650 degrees F.) and complete oxidation insured by a strongly oxidizing atmosphere.

This strongly oxidizing atmosphere is very necessary, and is attained by allowing a larger excess of air, over that required for the consumption of the fuel, to enter the kiln. However, the temperature must not be lowered in this process, but continue to be gradually raised, hence the regulation of the draft is very important and should be carefully taken care of. This requires considerable time, but its importance can not be too strongly emphasized.

To change all the iron to the ferric state, it is first necessary that the sulphur and carbon remaining in the clay is entirely oxidized. Sulphur usually occurs in combination with iron as pyrite, which has the composition of FeS_2. One of the atoms of sulphur is driven off at a low red heat, leaving FeS. This then must be completely changed to FeO, the ferrous oxide, before the ferric oxide, Fe_2O_3, can be formed. Free sulphur, and carbonaceous matter as well, are both reducing or deoxidizing agents. When they are present in a clay the iron is kept in the ferrous condition, both in the bank and in the kiln, until they are removed, because they take and use up all the oxygen before the iron can get a chance at it. Therefore, these elements must be oxidized and thereby removed before the iron can be oxidized, and if this has not been done by nature it must be in the kiln, and sufficient time must be allowed for these reactions to take place.

The texture of the clay is an important factor in its oxidation. The finer grained the clay the harder it is for the air with its oxygen to penetrate it; the longer time it takes for the oxides of carbon and

sulphur or other gases to escape, which prevent, during this escape, in a fined grained clay, the entrance of the oxygen. Orton shows that side-cut brick oxidize more quickly than end-cut, because of the larger roughened surface, and because the air can enter along the planes of lamination more easily. A striking example of the importance of texture is seen in one of the plants of this state which manufactures both stiff-mud and dry-press brick. The clay contains considerable sulphur. In the dry-press brick, the texture is loose enough so that all of the sulphurous gases can escape in burning, and a good brick of uniform red color can be made. In the stiff-mud brick, however, the sulphur is not all driven off in burning, and a brick with a black interior results. In the hollow brick, however, made by the same process and from the same clay, because of the increased surface and shorted distance through which the gases must penetrate, the sulphur is completely eliminated, and a homogeneous brick is the result. The texture of the clays and ware, as well as its composition, must therefore be taken into account in the burning.

The brick at the end of the oxidizing period should be a uniform color throughout, from surface to center, without cores of different shades. This may be determined by a test brick taken from the kiln at this period. Iron is seen to be the last element to oxidize, and if this is shown by the uniform color to be entirely in the ferric state, the next step may be safely begun. If not, it cannot begin, since ferrous oxide at high temperatures is a very strong flux, and if the temperature is raised while there is any present in the clay, the brick are apt to be slagged. It has been stated how gases, if sealed in by a vitrified surface, swell and bloat the brick. The last stage is carried on in a more or less reducing atmosphere, never in a strongly oxidizing one, and the color and appearance of the brick is thus largely determined by the completeness of the oxidation period. Dark greenish or black brick result from insufficient oxidation, or possibly a strongly reducing atmosphere in the last stage. The importance of oxidation is, therefore, very great, and in its completeness or incompleteness often lies the success or failure of the burned product.

Vitrification. The vitrification period is the finishing one, and has for its object the production of brick of the right strength and texture for the use to which it is to be put. As the temperature is raised above a bright red heat the clay shrinks and becomes dense. This is accomplished by a shrinking of the clay base, and the beginning of chemical union between the different elements compris-

ing the clay. The compounds first formed are the more fusible and as the temperature is raised they fuse and knit together the remaining particles of the clay. More and more compounds are continually being formed which in turn fuse until finally the clay loses all traces of its original structure and becomes a dense, uniform body, the point of complete vitrification[1]. If carried beyond this point the clay loses its shape and finally melts to a glass or slag. The brick or other ware is never carried beyond the point of vitrification and may be burned far below this temperature, depending on the purpose for which it is to be used.

The temperature at which these changes take place varies greatly for different clays, depending on their composition and texture. The impure varieties, those high in fluxes, begin to vitrify at 900 degrees C. (1650 degrees F.), rapidly become viscous and must not be carried far above that temperature. Paving brick, sewer pipe, and stoneware are burned at temperatures around 2300 degrees F., while fire brick must be carried even above 2500 degrees F. to give them the proper strength. In building brick it is desirable that they should be strong, but more or less porous, so as not to be so much affected by frost action. Paving brick should, on the other hand, be dense and not porous, and they are, therefore, raised to a higher temperature, as near as possible to complete vitrification. They should not be taken over this point else they will lose their shape, and also become brittle rather than tough. Provided the nature of the clay is known there is little danger of over-burning. The point at which the brick are withdrawn from the furnace may be determined by the use of Segar cones, or by the color, or most commonly, by the total shrinkage of the brick in the kiln.

The color of the burned brick is determined primarily by the composition, and also by the conditions in burning. Clays[2] with 4 to 5 per cent. of iron oxide become red; those with 2 to 3 per cent. buff, and those with less than 1 per cent. white or nearly so. Considerable lime counteracts the effect of the iron, and if clay which contains iron enough to burn red also has an excess of lime it will burn buff, gray or dark. Spotted clays, especially those containing concretions of iron and lime, unless thoroughly ground and mixed, have dark and white spots in the burned product.

The effect of oxidizing and reducing atmospheres has already been referred to, and ordinarily the color is much the same at the end of

[1] This process is more fully discussed in Chapter III of Part I, under Fusibility.
[2] H. Ries; New Jersey Geol. Survey, Vol. VI, p. 236.

the oxidizing period as it is when finished, although darker. However, it is impossible to maintain an oxidizing atmosphere in the kiln at a high temperature. Orton[1] states that the amount of free air must be cut down in order to raise the temperature for vitrification, so that the resulting gases are reducing or are possibly neutral at a temperature in the kiln of 1200 degrees C. (2200 degrees F.), or with gas fuel at 1300 degrees C. (2375 degrees F.).

The atmosphere may become strongly reducing by failure of the draft and smoky fires. The red ferric iron may thus be reduced to the ferrous condition, turning the brick gray, greenish, or black. Small grains of iron often become reduced, and at the elevated temperature combine with silica to form ferrous silicate, which slags easily and forms black blotches on the surface of the ware.

The surface of the brick may also, partly by reducing conditions, be changed to a different color, bright and brilliant; that is, they are "flashed." Bricks are often purposely flashed for use as front brick. This is accomplished by setting the brick so that the surfaces to be flashed are exposed to alternate oxidizing and reducing conditions, usually at the end of the burning, but sometimes through the entire period after water smoking.[2] The colors produced are superficial, and range from golden to red and brown shades, flashing being confined principally to buff-burning clays. The principal of this operation depends on the formation of ferruous silicate and ferrous oxide during the reducing conditions, and their partial reoxidization to the ferric oxide, which takes place probably during the cooling of the kiln.[3]

The degree of flashing depends on the following conditions:

(1) Composition and physical condition of the clay.

(2) Temperature of burning.

(3) Degree of reduction.

(4) Rate of cooling and amount of air then admitted to the kiln.

(1) The clay should be a buff-burning clay, and high enough in fluxes to vitrify at not too high a temperature. Clays high in silica flash better than those high in alumina. Those containing soluble iron compounds seem to flash better than those in which the iron is insoluble. A fine texture gives better results than a coarse one, and stiff-mud better than dry-press.

(2) The temperature must be high enough to cause a combination of iron and silica. It varies with different clays, the tempera-

[1] "On the Role Played by Iron in the Burning of Clays." T. A. C. S., Vol. V.
[2] H. Ries; New Jersey Geol. Survey, Vol. VI, p. 239.
[3] A. V. Bleininger; Notes on Flashing, T. A. C. S., Vol. II, p. 74. Quoted by H. Ries in N. J. Clay Report.

ture of combination being affected by the amount of fluxes present. The temperature could not be so high, if a reducing instead of an oxidizing atmosphere is kept during most of the burning, as the clay will vitrify sooner.

(3) A slightly reducing atmosphere must be kept during the last part of the burning, and the subsequent oxidation probably takes place in the first twelve hours after closing the kiln, when the amount of air admitted can be regulated entirely by the drafts.

(4) Also the slower the rate of cooling, down to approximately 700 degrees C. (1300 degrees F.), the darker the flash under the same conditions.

KILNS.[1]

There are many kinds of kilns in use today for burning brick. They are of four types, namely, up-draft, down-draft, muffle, and continuous. Each type has its own peculiar advantages and disadvantages which make it desirable or not for certain uses and under certain conditions.

Up-draft Kilns. The up-draft is the simplest type of kiln. The heat passes from the fireplace directly into the kiln at the bottom, rises through it, and escapes at the top. The temperature in a kiln of this type can not be regulated as well as in a down-draft, where the hot gases from the fireboxes are led through vertical flues to the top of the kiln, and passing down through the ware, escape at the bottom. For this and other reasons the up-draft kiln is used only for burning common brick.

The simplest kind of an up-draft kiln used in this country is the scove kiln. This is a temporary one, being built of the brick to be burned and torn down after each burning. The brick are piled up on a brick floor, about 40 or 50 courses high, by 15 to 30 feet wide, and from 20 to 40 feet in length. The bottom courses are set in parallel arches from 10 to 12 courses high, with two feet between centers, and running across the width of the kiln. (Plate XXX.) The walls are then built up around the green brick, made of old burnt brick, two or three courses thick, and daubed over with wet clay or "scoved," to prevent the entrance of cold air, and to insure the escape of the gases through the top. Openings are left in the side walls opposite the arches. Fires are built in the ends of these arches, fed through the openings, and pushed toward the center until

[1] Much of the material in this section has been taken from the pamphlet on Brick Kilns published by Richardson-Lovejoy Engineering Co., Columbus, Ohio, and also from the descriptions of Beyer and Williams in Iowa Geol. Survey, Vol XIV.

gradually the whole arch is filled with burning fuel. The gases rise through the brick, which must be set loosely, each course being at right angles with that below, and excapes at the top through the platting. The platting consists of a single layer of burned bricks laid close together. After the brick are burned the whole kiln is taken down.

An improvement over these temporary kilns are those having permanent walls. Sometimes these are nearly four or five feet high and contain the fireplaces. The rest of the kiln is of a temporary character and is built on top of these. Others have the entire side walls permanent, the kilns being filled and emptied from the ends.

The best forms have all the walls permanent, with a doorway at one end. (Plate XXXI). The brick are set in these the same as in the temporary one, openings in the side walls connecting with arches They may have permanent furnaces, each furnace furnishing heat for one or more arches. The most modern up-draft kilns have bottom flues built of fire brick under a perforated floor. The brick are set as in the down-draft kiln, uniformly over the whole floor, without any arches.

The up-draft kilns are much the cheaper both to build and to keep in repair, but they do not have an even distribution of heat, although this may be improved by mixing anthracite coal dust with the clay. There is a great waste of fuel, and a high temperature cannot be obtained.

The temporary scove kilns are cheap and can be built by ordinary labor; they have a large capacity, and the brick may be very conveniently handled. There is, however, a great loss from over-burned brick in the arches, and from soft unburned brick on top. There is also a very great waste of heat. These disadvantages are such that these kilns can only be used to burn common brick in yards which are run only a few months in the year, for it would be too expensive in such cases to have much money tied up in kilns which were idle the greater part of the time. The permanent kilns have a much more economical and better distribution of heat, especially those with bottom flues. This latter type is more expensive to build and keep in repair, but there is a great saving in labor and of loss from over-burned arch brick. Compared with other forms, the cheapness, convenience and rapidity of cooling makes the up-draft kilns desirable for burning common brick where a little waste of heat and loss from cracked and warped brick is not too expensive.

Their chief competitor is the continuous kiln, compared to which the cost of fuel for the up-draft is very large.

Down-draft Kilns. Down-draft kilns were devised to meet the need of better regulation of temperature, the production of higher temperatures, and more economy of fuel. They are circular or rectangular in shape, having an arched roof which reflects the heat downward through the kiln. The heat is generated in a fireplace or furnace, on the level of the kiln floor, and is led by means of a wall to the top. The gases are then deflected downward through the kiln, and drawn off through a system of flues under the floor to a central stack, or possibly to several chimneys. The hottest part of the kiln is at the top, and the brick here being under no load are less liable to be deformed than if the highest temperature was at the bottom, as in up-draft kilns, where the bottom courses support the weight of the entire kiln of brick. Higher temperatures can thus be used, the distribution of the heat is more even, and by regulation of the draft the distribution of heat is ever under control. The down-draft kiln is greatly to be preferred to the up-draft in the burning of high grade brick, harder and more uniform burns can be obtained, with less care and skill, and with a smaller amount of fuel.

There are a great many kinds of down-draft kilns, each built to secure better results under different conditions. The chief differences lie in the construction of the fireplace, the arrangement of the bottom flues, their communication with the stack or stacks, and the regulation of the draft in different parts of the kiln by means of dampers.

The round kilns are the most common for burning all kinds of ware. They are some 20 to 30 feet or more in diameter and six to seven feet high to the beginning of the arch, which has a height of some four to six feet. They hold from 50,000 to 80,000 standard brick. They are less expensive to build and to keep in repair than rectangular kilns, and there is a more uniform distribution of gases. They are not, however, so economical as regards yard space, capacity and fuel, and neither are they so convenient in handling, setting and drawing the brick.

They were first built with merely one center draft well, which was connected with a single stack. The heat as it entered the kiln sought the shortest and easiest path to the outlet, and in consequence, if the center of these kilns were correctly burned, the surrounding brick were under-burned, or if the outside brick were burned properly the center was over-burned. With side openings leading into side

stacks, the reverse was true. To overcome this difficulty there have been designed a great number of arrangements of outlet wells which are distributed over the bottom. The most common is by means of a system of radial flues, with openings leading to a central flue which is directly connected with the stack. The openings are larger the further they are from the center, as the gases tend to pass out the center of the kiln, and this arrangement insures a more equal apportioning of the flue gases.

In order to give a uniform temperature to the very bottom of the kiln, false floors are most always used. If these floors were not used the temperature would be unevenly distributed at the bottom of the kiln, as the gases are divided just as they pass into the flue openings. Formerly green brick were used. They were set as openly as possible, yet having the requisite strength to afford free passage for the gases to the outlets. This is now replaced by permanent false floors, to obviate the extra labor of resetting the green brick after each burn. These floors are built of fire brick, of special design, and are called checker floors. They insure a nearly uniform temperature directly to the bottom of the kiln. There is a loss of heat from the necessity of bringing the checker floors to the temperature of the kiln, but this is more than offset by the more successful burning.

It is also essential, in order to produce the same temperature at the bottom of the kiln as at the top, that the draft should be brisk so that the hot gases should be brought rapidly to the bottom before they have a chance to cool to any extent. This is accomplished by means of a good stack. The tendency at present is to have one central chimney for two, or possibly more, kilns. The flues leading to it should be shallow and as short as possible. The central stack should be partitioned part way, so that each kiln will discharge into a separate compartment. One central stack is of great advantage, in that the cost of construction is less for the most efficient draft, and by the union of flues into one stack a burning kiln helps to furnish a draft in a kiln which is just being started.

One type of round kiln is built with a stack located in the center of the kiln. This has many advantages. The draft is quickly started as the stack becomes heated, thus giving rapidity of burning; then, too, the hot stack helps to bring the center of the kiln to the required heat as soon as the sides, and at the same time permitting a stronger draft to the sides. There are no horizontal flues, only the radial ones leading directly to the stack. The cost of construction is less, as no outside flues are built, and the dimensions of the stack

do not have to be so great to give the same draft as an outside stack, as it is kept highly heated and is, therefore, more effective. The space outside the kilns is also free. The objections are that the kiln room is taken up by the stack, but this does not amount to much, especially in a large kiln. For one 30 feet in diameter only about 2.5 per cent. of the available kiln space is occupied by the stack, and for a 36-foot kiln about 2.2 per cent.[1] The stack is somewhat in the way during the setting and drawing of the brick, especially when cars are used, and care must be taken that the foundation of the stack is of the strongest and best construction, as it is subjected to the most intense heat of the kiln. The advantages, together with saving of fuel and facility of operation, more than over-balance the objections, and the kiln is claimed to give a better burn, and in 24 to 48 hours less time, than any other down-draft kiln in use today.

The dampers used to control the draft in down-draft kilns are of two types, sliding and hinged. They are built of sheet iron, or better, of fire clay held in iron frames. They are operated by hand and should be very efficient to be of much value. With outside stacks either horizontal or vertical slide dampers are used, but because of the very strong draft in center stacks side-hinged, valve dampers are employed. (See Plate XXXII.)

Round kilns are best for general purposes. They burn a larger percentage of hard uniform brick. They are particularly adapted to burning paving brick and face brick, where uniformity of product is essential.

Rectangular kilns are built with capacities of 150,000 to 200,000 brick, and they are great economizers of space. The brick may be handled most conveniently and in these large kilns there is a considerable saving in fuel and labor. On the other hand the heat can not be so evenly distributed, and the kilns are more expensive to build and to keep in repair. They are from 15 to 20 feet wide and 50 to 75 feet long, although some have a length of 100 feet. They are built with slanting or straight side walls. The latter have to be braced by steel beams and tie rods, which add greatly to the expense. (See plates XXXIII and XXXIV.)

The draft system is necessarily arranged differently from that of the round kiln. Single stacks for two or more kilns are most commonly built at present, although formerly multiple-stack kilns were built, and are extensively used today. Side stacks are preferred to end stacks, as in the latter the heat tends to collect near the stack

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[1] Richardson-Lovejoy: "Brick Kilns."

Scove kilns at Drayton Brick Plant, showing method of setting brick.

Scove kiln with permanent side walls, at Wilton Brick Plant.

Fig. 1. Kilns at Breuggar's Brick Plant at Williston.

Fig. 2. Round down-draft kilns of Kenmare Hard Coal, Brick and Tile Company.

Building a down-draft kiln at Wilton, showing the central flue.

Interior of down-draft kiln at Hebron, showing method of setting face brick and false floor.

end. The flue system, with single stack kilns, is divided into two or more, usually three, parts, each regulated by a separate damper. The heat may thus be directed to any part of the kiln desired. With multiple stacks the flue system is divided into as many parts as there are stacks, each one controlling a definite part of the furnace more or less independently of the others. Such an arrangement is difficult to manage, and is not susceptible of any better results than the single stack. Center stacks, as in the round kiln, are used with the same advantages. A rectangular kiln of ordinary or greater length requires two or more interior stacks for good control of the temperature. The amount of available space taken up is small and the method is capable of saving, although they have not as yet come into general use. Perforated false floors are employed to insure an even temperature to the bottom of the kiln. With the modern improved square down-draft kiln there is a great saving of fuel and labor, an increased capacity, and they can be used to great advantage for burning face brick and paving brick, which vitrify easily.

Muffle Kilns. Muffle kilns are designed to burn ware such as pottery, terra cotta, enameled brick, and tile, which can not be burned in contact with the furnace gases. Flashing of the ware and discoloration of the glazes are apt to occur, which is very detrimental to the value of the ware. They must, therefore, be heated and at the same time protected from the flames. This is accomplished by the use of saggers or muffle kilns.

Small wares, such as tile and small pieces of pottery, can be enclosed in saggers, which are flat, cylindrical vessels of fire clay. After the ware has been placed in the saggers they are sealed with clay, and are set in a regular down-draft kiln and burned in the usual manner. This method accomplishes the work of the muffle, with much less waste of heat, but it is not, of course, applicable to large pieces of ware.

In muffle kilns the ware is placed in chambers which are entirely or partly (semi-muffle kilns) screened from the fire gases. The loss of heat in these kilns is necessarily very large, and they should only be used where the value of the ware is considerable, and where this treatment is essential. They are of up-draft and down-draft types, the latter being by far the most common. The down-draft muffle kiln resembles the regular down-draft kiln, inside of which is a sealed chamber and space between the two for the circulation of the gases. The object of the different types is to keep the gases in contact with the surface of the muffle as long as possible, and

also to increase the surface of muffle compared to the space inside the muffle. This space can never be very large, as otherwise a uniform temperature could not be maintained. In the best types the heat is led into a circular space surrounding the muffle, thence between the two crowns down through a central opening to radial flues just beneath the floor, and thence escapes by means of several chimneys. In an improved type, the gases are circulated beneath the floor and are then returned to a center stack which is inside of the central space through which the gases are brought from the crown of the kiln to the floor.

Continuous Kilns. Continuous kilns have for their chief object the economy of fuel, by utilizing all the waste heat possible. The greater portion of the latter, which is ordinarily allowed to escape into the air through the stack, and that of the cooling kilns is saved by the use of a continuous kiln.

The principal by which this is accomplished is to lead, by means of a system of flues, the heat generated in one kiln through a series of chambers in front of the one, and then when all of the heat possible to obtain from the gases has been abstracted they are allowed to escape through the stack.

They consist of series of compartments, circular, oval, or rectangular in shape. Each compartment is connected with the next in line, and with a central stack, by means of flues. In some, the chambers are separated by permanent brick walls, while in others wood or paper partitions are used, which are burnt out when the temperature reaches a red heat. In some types an up-draft is used, and in others a down-draft.

A fire is started in one compartment by means of exterior fire boxes, and while the water smoking period is taking place the gases are allowed to go directly to the stack. After all the water has been driven off the heat passes into and through the chamber ahead and thereon to the stack. When the most of the water has been driven from the second compartment the heat goes to the one further on, so that when the kiln is running properly the heat passes through several chambers ahead of the burning ones before it escapes into the air. When one chamber gets red hot, fuel in the form of coal slack is introduced through small openings in the top of the kiln, the ware being set so that the fuel thus fed is distributed through the kiln from top to bottom by collecting on ledges of projecting brick in different courses. It is thus possible to burn brick in some chambers, and gradually heat up those in front while those behind

are cooling off. The chambers opposite to these of maximum temperature are at the same time being filled or emptied. Thus a sort of wave of maximum temperature is continually passing around the kiln.

The limit to which the gases may be carried ahead of the fire is that point at which they become saturated with water vapor. At this point, or rather shortly before, the gases must be allowed to pass to the stack, otherwise the brick will be scummed, as these always contain acid vapors derived from the burning coal, and from the impure clays at higher temperatures. To obviate the danger of scumming, independent flues are built which take the gases from the cooling kilns, which are, of course, free from acid vapors, and employ them for water smoking. However, the gases must be turned into the stack before they are cooled too much, for they must furnish the energy to create the draft necessary to circulate the gases through the rather long and complex system of flues. For this reason the stacks must be higher and larger than those used for ordinary kilns. To the same end they are usually placed at the center of the kilns or at one end, and the flues leading into them are carried just under the level of the floor.

Higher grade wares than common brick cannot usually be burned by fuel in contact with it. For this class of ware, therefore, furnaces are used. Also outside auxiliary furnaces are desirable for better regulation of temperature, for sometimes it is necessary to increase or decrease the speed of burning.

The continuous kiln has, therefore, the great advantage of saving of fuel, which amounts to 60 to 70 per cent, and more convenience of handling the fuel and of burning. There is no annoyance from smoke and gases, a factor that is important in populous districts. It can be operated in all weather and gives a good percentage of hard burnt brick. The disadvantages are the extra cost of construction and repairs, the extra labor required for setting and drawing, the unsanitary conditions under which the men work in hot, close chambers, and they must be operated continuously to secure their full economy. These relative advantages and disadvantages make them of particular value in Germany, where fuel is expensive and labor cheap. While as yet their development in the United States is not extensive, it is on the increase.

Continuous kilns are of three types: (1) open top, (2) annular, and (3) chambered. The open top kiln is the adoption of the continuous principal to the permanent up-draft kiln. It is cheap to

build, has the advantage of saving fuel, and yet is not unsanitary. This kiln is adapted to burn common brick.

Annular kilns are the common type, and usually consist of a circular arched tunnel. The fuel is fed into it through the roof. They may take off the gases from the bottom or from the top. It is more expensive to build than the open top kiln, but has a greater saving of fuel and is the one usually employed for burning common brick in Europe.

Chambered kilns combine the advantage of down-draft kilns with those of the continuous kiln. They may be fired through the roof, or by separate furnaces. In them high grade wares may be properly burned. An adaption of this type is the semi-continuous kiln, which while it has the advantage of almost as great a saving of fuel as the continuous kiln, yet is arranged more simply and is regulated conveniently and easily.

In this country common brick are successfully burned in the continuous kiln, but it has been more or less of a failure in the burning of paving brick and other wares. Yet in Germany it is used to burn all classes of ware, from common brick to porcelain, with great economy. The reason for the failure in America was shown to be due by the investigation of the American Ceramic Society in 1901 to the following points.[1]

1. "The American clay worker has not devoted himself to the study of the continuous kiln, in its adaptation to American clays.

2. "The burning chambers are built too high and too wide. The best German kilns for the finer wares have chambers seven feet wide by six feet high.

3. "The fuel is almost invariably distributed among the ware, which will not be satisfactory for anything but common brick.

4. "The kiln is worked too hard. The waste gases are drawn so far through green ware that condensation and consequent scumming are produced.

5. "The almost invariable use of underground flues. They produce a poor and variable draft.

6. "In most instances the water smoke is taken from the bottom of the kiln, while it is best taken from the top.

7. "The continuous kiln should be erected by engineers properly trained for that work."

[1] "Defects of the Continuous Kilns of Today and Prospective Improvements," T. A. C. S., Vol. III, p. 205. Quoted in Iowa Geol. Survey, Vol. XIV, p. 318.

The suggestions given here for improvement, as well as others, have been carried out and continuous kilns will come into greater use.

FUELS.

Wood, coal, oil and gas are all used to burn brick. They each have their respective advantages which makes them adapted to certain stages of burning or to certain classes of ware. However, it is the location of the plant which determines the fuel used, as that which is most easily and cheaply obtained is usually employed.

Wood. Wood is exclusively used in the eastern part of North Dakota to burn common brick. It has several advantages. It is easily started, and the temperature very gradually raised, and with good control of the rising temperature. Its gases are free from sulphur and other harmful constituents, and so by its use the danger of scumming is avoided. These facts make wood very desirable to begin with, and when coal is employed for the major part of the burning wood is very often used for the period of hydration. However, the gases contain a large percentage of water vapor, as wood is rich in hydrogen, and care must be taken to insure a good draft while the hygroscopic moisture is being driven off. Wood furnishes a long flame desirable for kiln burning, and is particularly adapted for use in some kilns where the fire is built in the arches. It is easily fed and a fairly hot fire can be easily made and controlled, the temperatures in the different parts of the kiln thus being somewhat under control. It therefore corrects the faults of these temporary kilns to some degree and is almost universally used for burning common brick in some kilns.

Coal. Coal is the most common of all the fuels used. To furnish the largest possible heat, and for proper regulation, it must be burned in a furnace. There are three types of furnaces in common use:[1] (1) the flat grate bar, (2) the inclined grate bar, and (3) the dead bottom fire. The flat grate bar furnace is the most common. The grate is horizontal and the fuel evenly distributed over it. The air from below passes through the grate and fuel and thus the thickness of the fuel on the grate regulates the amount of air passing into the furnace. The proper regulation is rather a difficult matter. Enough air should pass through to oxidize all the volatile combustible gases and the carbon, but if the layer of fuel becomes too thick, not enough air is furnished and smoky reducing fires result, and

[1] Iowa Geol. Survey, Vol. XIV, p. 269.

combustible gases and carbon pass out of the stack, which is very wasteful. If the layer of fuel on the grate becomes too thin, whereas enough air is furnished, it is likely to burn through in holes, and cold air then rushes into the kiln through these holes and cools the kiln. However, will skillful and careful firing, and the best regulation of temperature and atmosphere, the most efficient economy is obtained by the use of the flat grate bar furnace.

In order to completely burn the volatile and combustible gases which are distilled from coal when it is first heated, and which ordinarily escape through the stacks, coking tables are used. The coking tables consist of a heavy sheet-iron plate, or better, a slab of fire clay situated in front of the grate, and about one-third of the grate area. The fresh coal is fed onto the coking plate and the radiation from the burning fuel drives off the volatile gases, which are ignited by passing over the burning coal, and burn in the kiln. The fixed carbon or coke left after the gases have been distilled off is pushed onto the grate, where it takes fire and burns. The coking table thus saves the heat of combustion of the volatile gases, and the coke on the grate burns without smoking, and therefore clean, hot fires are possible. This is especially applicable to coals rich in volitale matter, as soft coals and lignites.

Another method for burning lignite is used in North Dakota, which was devised by Mr. Russell, superintendent of the Dickinson brick plant. It consists of building long fire boxes covered with arches of fire clay. These arches are raised to a white heat, and the gases as they are driven off and pass through the furnace are ignited by the hot arches. With these arches a perfectly smokeless fire and very high temperature may be obtained.

In the inclined grate bar furnaces the grate bars are sloped downward from the fire door to the back of the furnace. They do not, however, reach clear to the back wall, but are supported by a horizontal bar running across the furnace six inches to a foot above the bottom of the ash pit. The fire is started on the bottom of the ash pit, beyond the ends of the grate bars, and is gradually built up to the grate, and finally covers it. The air which enters the furnace below the grate is, at first, when there is no fuel on the grate, very brisk, but gradually decreases as the grate becomes covered with coal. The temperature rises accordingly as the fire grows larger and the draft smaller, but as the change progresses slowly the ware is fully prepared for the gradual increase in temperature. There is little danger of the fire burning through in holes, the grate is easily

kept free of clinkers, and the draft regulated. The great care and skilled firing necessary with the flat grate is not required, but the method is not capable of so perfect regulation or economy. Also during cooling the gases from the pile of coal left in the bottom of the furnace enter the kiln, and as coal practically always contains sulphur these may be harmful.

With the dead bottom fire, grate bars are not used at all. The fire is started against some loosely piled brick in the ash pit, the draft entering the ash pit doors, and the fuel being fed from above. The fuel is heaped up until it is above the ash pit door when air is also admitted through the fuel door, and sometimes by auxiliary openings in the neck of the furnace. As the fire grows larger the draft becomes smaller and the temperature correspondingly higher. To burn satisfactorily the coal should form a strong porous clinker, which falls into an inclined heap, and plays the same part as an inclined grate. The air in the later stages of burning passing through the fuel is insufficient for complete combustion and holes have to be poked through the heap. This causes alternating oxidizing and reducing conditions in the kiln, and whereas this is desirable in flashing brick it is not ordinarily where a uniform burn is desired. The advantage of this method is the cheapness, especially of repairs. Any grade of coal that clinkers may be used, and unskilled firing may be also employed without harm. It is open to the objection of the inclined grate that sulphurous gases enter the cooling kiln, and also the conditions are not uniform.

All the different kinds of coal are employed for burning clay; bituminous coal is the most common, anthracite is used somewhat, and in certain sections of the country, and notably in North Dakota, lignite is very important. Anthracite coal has practically no flame but is capable of producing a great heat, but though it is not used alone is often used with bituminous coal.

Bituminous coals are of several grades, from short flame, smokeless, semi-anthracite coals, to those with a large percentage of volatile gases, which burn easily with a large flame and considerable smoke. With the higher grades of bituminous coal, those with short flame, it is necessary to use a very considerable draft to carry the heat uniformly through the kiln, and it is also difficult to heat the kiln slowly through the period of hydration, and with smoky coals the passages are apt to get clogged with soot, and wood is often therefore used to start the burning. Fat, long flame and steam coals are better than short flame coals for burning where the draft

is poor, especially in up-draft kilns, short flame coals requiring a forced draft. Sulphur is about the only harmful constituent of coal, the sulphur coating the clay during the period of hydration and cooling. In the large clay centers bituminous coal is the cheapest fuel obtainable and is employed most extensively.

In North Dakota, lignite, which underlies the western half of the state, is the fuel used in most of the brick plants, except those which manufacture common brick in the Red River Valley. Lignite is lower in fixed carbon than the better grades of bituminous coal, but higher in volatile combustible gases, which add greatly to its heating values when properly burned. The percentage of ash is generally very low, leaving merely a gray powery residue, like that formed from wood. The sulphur is much lower than in bituminous coals, being usually less than 1 per cent. The chief objection to the lignite is the high percentage of moisture and the tendancy, when drying, to slack to a fine state in the air. Those who have used other coals prefer the lignite for some purposes. It may be used for water smoking, as it has advantages similar to those of wood, and as it is comparatively free from sulphur there is no danger of scumming. There is no change of fuel from the hydration period to those of oxidation and vitrification. At very high temperatures, however, proper regulation is more difficult than with bituminous coal. The lignite is at present burned in lump form in flat grate bars with incandescent arches, care being taken to keep the lignite under cover so that it will not dry and slack.[1]

Professor Babcock has advocated the burning of lignite in a powdered form with an air blast, and this method would doubtless have some of the advantages of a gas fuel.

Oil and Gas. In plants where oil and natural gas can be procured cheap they are used for burning brick. The use of these for fuel has many advantages, chiefly mechanical. There is a great saving of labor in the handling, and a greater precision in the regulation of the temperature, and of the nature of the gases. By the amount of air mixed with the fuel in the burner the flame may be made reducing, or oxidizing. An oxidizing atmosphere can be maintained at a higher temperature than with solid fuel; with coal only 1200 degrees C. (2200 degrees F.), while with gas 1300 degrees C. (2375 F.) can be obtained. Thus better and more uniform burns can be obtained with a liquid and gaseous fuel than with solid.

[1] For a fuller discussion of the worth of lignite as a fuel, see N. Dak. Geol. Survey, Vol. II, pp. 168-197.

In regions where oil or natural gas are out of the question, producer gas may be generated and used. Producer gas has all the advantages of gaseous fuel. A little more coal is consumed than where the kiln is directly fired, but the cleanliness, the more uniform burns, the saving of labor and repairs, more than offset the cost of the additional fuel required. Lignite has been shown to be an excellent gas producing fuel, and it will doubtless be much used in this form for burning kilns in the future.

CHAPTER XIII.

THE NORTH DAKOTA BRICK INDUSTRY.

DEVELOPMENT OF THE INDUSTRY.

The clay industry of the state is confined almost entirely to the production of brick. Common brick were probably first manufactured at Fargo some time in the seventies. The industry spread through the Red River Valley, so that by 1885 plants were in operation at Fargo, Grand Forks and Minto. Grand Forks took the lead in the production, two plants being started in the early eighties, one by Wm. Budge and another by W. P. Alsip. The industry developed rapidly there, and at present four plants are in operation in Grand Forks. Brick have been also made at several other places in the valley, namely, at Walhalla and Grafton, and are manufactured at present in Drayton, Hillsboro, Fargo and Abercrombie. Brick plants were early started at Mandan and Jamestown on the Northern Pacific, and at Minot and Williston on the Great Northern railroad. All these plants and several others manufactured only common brick by the soft-mud process, using surface clay and burning the brick in scove kilns.

Cretaceous clays were probably first used at Dickinson, where as early as 1892 common brick was manufactured from the Laramie clays. Brick were also made later at New Salem from these clays. With the building of the Soo railroad the coal mines in Ward county were developed and brick plants were established at Kenmare, Donnybrook, Burlington and Velva, all using the Laramie clays. Those at Kenmare and Burlington are still in operation. A stiff-mud machine was installed at Kenmare in 1903 and common brick have been made since then on a large scale, being burnt in permanent up-draft and in round down-draft kilns.

Pressed brick were first manufactured at Dickinson on the site of the present plant in 1893 by the Dakota Land and Improvement company. The plant was in operation almost two years. The high grade, light burning clays were used with a dry press, but the brick were probably burned in scove kilns. Brick were also made at this time by the stiff-mud process from the same clays several miles north of Dickinson. The pressed brick plant was idle from

1897 to 1898, when Professor M. A. Brannon of the State University bought up the plant and first manufactured front brick on a permanent basis. The Dickinson Pressed and Fire Brick company was organized later and developed the same property more fully. Since then pressed brick plants have been established at Hebron, Mayo, Kenmare and Wilton. Repressed front brick are also made at Richardton. The Hebron plant uses the Tertiary light-burning clays and manufactures fire as well as front brick.

THE PRESENT INDUSTRY.

There were eighteen plants in operation in the state in 1906, but three of the other smaller ones were shut dawn. The statistics collected were for the year of 1905.

All of the plants produce common brick. The chief center for the common brick industry is Grand Forks, where the Red River Valley Brick company operates four plants, one of them, however, being located on the Minnesota side of the river. The Grand Forks Brick, Tile and Cement company opened up a new plant in 1906. The brick is cream colored and is manufactured by the soft-mud process, dried in pallet racks, and burned in scove kilns with wood fuel.

The clay underlying the black surface loam is used. From eight inches to a foot of loam is scraped off and the underlying three feet of yellow clay and about a foot of blue and yellow "joint clay" is shoveled directly into two-wheeled dump carts, which take the clay to the pug mill. The pits are broad and shallow, and are worked sometimes in two benches for convenience in handling. The clay is fed directly into the pug mill, from which it goes to the brick machine. All of the plants at Grand Forks use the Wellington Quaker soft brick machine, with a capacity of 45,000 brick per day. The brick are dried in very large yards with covered pallet racks, each yard having a capacity of about 300,000 brick. The latter are dried from six to seven days, and then burned in scove kilns with wood for fuel. At the Alsip yard four down-draft kilns were built during the past season but were not successful. The clay dries and burns readily, giving a hard, cream brick, which is very porous but is very good for common structural purposes. About thirty men are employed at each plant, and they are in operation from the first of May to September first.

Other yards using the yellow subsoil of the valley are located at Drayton, Fargo and Abercrombie. The Drayton plant is very

similar in its equipment and method of manufacture to those at Grand Forks. At Fargo there are two plants. Here the clay is tempered in soak pits before going to the brick machine. Anderson Brothers use a power brick machine, the Martin, and the Fargo Brick Company horse power machines. The brick are dried in open yards, the Anderson yard using pallets. The brick are dried flat for a day, then turned up on edge for half a day, and are then piled in hacks and the drying completed in three or four days longer. They are burned in scove kilns, which are built only thirty-eight courses high and fired with wood fuel. A good cream-colored brick is obtained, similar to the Grand Forks product. The plant at Abercrombie is smaller and did not produce any brick in 1906. A horse power slob-brick machine is used, the brick being dried in covered sheds and burned in small scove kilns. All these plants are in operation only about four months of the year.

The plant at Hillsboro was reopened in 1906 with a new equipment similar to the Grand Forks yards. The material used here is an alluvial clay obtained from the flood plain of the Goose river. It is lower in lime than the lacustrine clays of the valley, and the Hillsboro brick is light red.

Other plants using alluvial clay are situated at Williston, Minot and Mandan. At Williston a power soft-mud brick machine is used, with a capacity of 25,000 per day. The brick are dried on covered pallet racks and burned in scove kilns. One round down-draft kiln is also used with good success. The brick are a light red. At Minot soft-mud brick are made from clay taken from the Mouse river flat. The plant has the equipment for stiff-mud brick, and the present owner plans to make them in 1907. The brick are dried in pallet racks and burned in scove kilns, with lignite as a fuel. The product has a good red color but is rather soft. At Mandan the brick are moulded by hand. The clay is first prepared by tempering over night in a soak pit, and in a short, vertical pug mill. The brick are dried in open yards and burned in scove kilns with wood fuel. They are red and porous but quite strong. The above plants are only in operation in the summer season, usually about four months.

Soft-mud common brick are made at several other towns in the state, namely, at Omemee, Rolla, Bismarck, Richardton and Burlington. The plant at Omemee is located three miles north of the town at Hall's Spur. The yellow clay subsoil from the bottom of

Plant of the Hebron Pressed and Fire Brick Company.

the old glacial Lake Souris is used. Power for a soft-mud brick machine is furnished by a threshing engine, which is also used at several of the other plants. The brick are dried on pallet racks and burned in scove kilns or in a permanent up-draft kiln, wood being used for fuel. The bricks burn red and are very soft. This plant was not in operation in 1906. At Rolla the yellow glacial clay underlying the black surface loam is used, the brick being a cream color due to the large amount of lime. The only ring pit in the state is here employed to temper the clay, which is tough and lumpy. The soft-mud brick are dried on pallets and burned in a scove kiln with wood, the product being fairly strong. The clay is dug in a hollow surrounded by low elevations and in wet seasons the pits are full of water, and for this reason the plant was idle during the past season. At Bismarck a plant is operated by the state with convict labor. Glacial till is used which is tempered over night in soak pits before going to the machines. The brick are dried in an open yard and burned in up-draft kilns with permanent fire holes and side walls about three feet high, using lignite for fuel. Very good, strong and fairly dense red brick are made. A few are repressed in a hand press for facing. At Richardton glacial till and Laramie clays are both used for the manufacture of red brick, most of which are used by the Catholic college at that place. The clay is soaked over night in pits, is molded in a horse power brick machine, and dried partly in an open yard and partly in a covered shed. Repress brick are also made. The brick are burned in up-draft kilns, lignite being used for fuel. The product is strong and of a light red color. A very good grade of common brick is made from the Laramie clays at Burlington by the Mouse River Lignite Coal Company. The whole bank of clay exposed by the Mouse river is mined, being undercut by plows and scrapers. The material is crushed in a roll crusher and then goes to the pug mill of a horizontal brick machine—the Anderson. The brick are dried on pallet racks and burned in scove kilns. Lignite is mined on the spot and employed for burning. This plant is one of the larger ones and has a fairly good production. It was not in operation in 1906 but is to be reopened, possibly on a larger scale, in 1907. In all the plants so far described the equipment is such that they can only be in operation four or five months in the year.

There are five plants in the state that are equipped to run the major part of the year. The plant at Kenmare, operated by the Kenmare Hard Coal and Brick company, has the largest output,

mainly common brick but dry-press front brick are also produced. The clay is mined by undercutting the steep bank with pick and shovel. The surface is plowed and scraped off and the rest of the bank, consisting of Laramie sands and clay, with a few feet of glacial till, becomes mixed together. The clay is shoveled into wheelbarrows, dumped into a chute emptying into a car, and hauled up to the plant on an incline by a cable. The clay is crushed in smooth rolls and in a pulverizer. A stiff-mud machine is used, the clay column being side cut. The brick are dried in a continuous tunnel drier and take about thirty-six hours to go through. Waste steam is used to heat the drier. The brick are then burned in up-draft kilns, but are soon to be burned entirely in square down-draft kilns. Dry-pressed brick are also made from the same clay, which is first dried on a steam drying floor. The pressed brick are burned in round down-draft kilns. Lignite mined by the same company is used for fuel. The brick are light red to greenish in color and fairly strong.

Laramie clay shale underlying the coal seam mined by the Washburn Lignite Coal Company at Wilton is used for the manufacture of stiff-mud and dry-press brick. The clay is mined by much the same method as the coal—the butt entry system. The clay underlies the coal, eight to ten feet of clay being mined and the coal used for a roof. There are two pits, one on the south side and another on the north side of the shaft. The clay is undercut by electric coal-cutting machines and then shot down. It is trammed out to the shaft by mules and after being hoisted is dumped near the crushing machinery. It is crushed in a dry pan, after being dried and weathered on the dump pile for three or four days. From the dry pan the clay is elevated and screened, the oversize returning to the pan and the undersize going to the machines. Dry-press and stiff-mud brick are both made. The stiff-mud, side-cut brick are dried in open yards, being hacked directly from the machine, and burned in permanent up-draft kilns, lignite being used for fuel. The dry-press brick are burned in rectangular down-draft kilns of the Flood type. This plant opened up in 1906, and with its large equipment should have a very good production and successful future.

The only plant in the state utilizing the Cretaceous shales is the one at Mayo, five miles west of Walhalla. The Pembina river exposes here the Niobrara and Benton shales, the latter being used. Stiff-mud end-cut, hollow, and dry-press brick are manufactured.

Mayo Brick Plant, showing the Niobrara and Benton shales in the background.

The clay is dried in sheds—weathered shale is used for the stiff-mud process—crushed in a dry pan, and after being screened goes to the molding machinery. All the brick produced to date have been dried in open yards and burned in scove kilns with wood. A ten-tunnel steam drier is being built and round down-draft kilns are to be erected. As yet, although the plant has been established for two years, the production has been small, as the owners have been waiting for the advent of a railroad which has been promised. The brick is of a very good red color and an otherwise good product can be obtained. (Plate XXXV).

There are at present two plants which are using the refractory, light-burning Tertiary clays. These are situated at Dickinson and Hebron. The Dickinson plant is equipped to make dry-press, stiff-mud and repress brick, but most attention is paid to the production of the dry-press brick. Common, face and fire brick are all manufactured by this process. The clay is obtained from the top of a butte a mile southwest of the town and hauled to the plant in carts. For common brick the clay in a pit just back of the plant and associated with the lignite is mixed with higher grade clay. It is then carried over the Heart river and up to the plant in cars on an inclined railway. The clay goes directly to the pan crusher, and from there to the press. The pressed brick are set directly in the kilns, the common brick being burned in scove kilns and the front and fire brick in rectangular down-draft kilns. The front and fire brick are burned with lignite at a very high temperature, which is necessary because of the refractory nature of the clay. The common brick is salmon colored, the front brick white, buff, spotted and flashed. Stiff-mud and repressed brick as well as special fire clay shapes are also manufactured. The product of this plant is very high grade and in good demand.

At Hebron another plant using the Tertiary clay was established in the spring of 1905 and has just finished a prosperous year. The clay is mined some five miles north of town. It has been hauled to the plant, which is located beside the railroad, the last two seasons in wagons, but a steam tram has just been completed to haul the clay. The clay is stored and sweated in bins before using. It is then crushed in a dry pan and the brick, except the fire brick, are manufactured by the dry-press process. They are burned at high temperatures in Flood rectangular down-draft kilns with lignite for fuel. Buff, mottled, gray and flashed face brick are made. Fire brick are molded by the soft-mud process and repressed by hand.

The product from this plant is of a very high order and is a good example of what can be done with the high grade North Dakota clays.

PHYSICAL TESTS OF NORTH DAKOTA BUILDING BRICK.

A series of tests were made on the North Dakota brick to show the grade of the product for purposes of comparison with brick manufactured in other states, and to inform the manufacturers in this state of the relative grade of their brick. From lack of funds to carry them on these tests were incomplete, in that a large number of brick from each manufacturer should be tested in order to secure the most reliable results. This it was impossible to do with the common brick, but the attempt has been made to show the approximate strength and the relative value of the brick. The tests on the dry-press brick were more complete and hence more valuable.

Physical testing in the laboratory has lately been recognized to be a very good and efficient method of determining the grade of a brick. The National Brick Makers' Association has therefore investigated the matter and adopted a series of standard tests, so that comparisons between bricks tested by different observers would be of value. Such tests also detect faults in the process of manufacture, so that having been thus revealed they may be corrected.

The tests usually applied to common brick and front brick are the determination of the transverse and crushing strength, the absorption, and the strength after repeated freezings and thawings. In testing paving brick the rattler test to determine the abrasive qualities is the most important. In testing the North Dakota brick the transverse and crushing strength and the percentage of absorption were determined. The strength tests were carried on by Professor Calvin H. Crouch in the laboratory of mechanical engineering of the State University, and the absorption tests were made by the writer.

Professor Crouch describes as follows the manner of making the strength tests: "The transverse tests were made by placing the brick edgewise on two supports or knife edges, placed six inches apart, and applying the load by another knife edge on top of the brick placed midway between the supporting edges. The knife edges should be rounded to one-eighth of an inch radius and raised at the center to compensate for any warping of the brick. The breaking load is noted and the modulus of rupture calculated. This modulus, given in pounds per square inch, is the maximum tensile

stress in any portion of the brick due to flexure. It is determined by means of the following formula:

$$R = \frac{3WL}{2bh^2}$$

R = modulus.
W = load at breaking.
L = distance between supports.
b = horizontal dimension of the brick (thickness).
h = vertical dimensions of the brick (breadth).

The compression or crushing tests were made by crushing one-half of a brick that had been broken in flexure. These portions of brick were dressed so as to be approximately rectangular in shape and the area of the surface measured. To insure uniform pressure on all parts of the surfaces to which pressures were applied, the bricks were covered with a coat or layer of plaster of Paris on these two sides. They were then placed in the Riehle testing machine, a slight pressure (2,000 pounds or less) was applied and they were allowed to stand until the plaster of Paris had hardened, when pressure was applied and the brick crushed. The pressure was observed when the brick first cracked, again when the brick failed completely, and the respective pressure in pounds per square inch was calculated."

For the very best results it is doubtless best that the crushing tests should be made upon two-inch cubes, with steel bearing plates;[1] but very good results were obtained by setting the brick in plaster of Paris. It is not necessary that the brick should set in the plaster more than twenty minutes before breaking. Tests were made on brick which had set over night and on others which had set only twenty minutes and no appreciable difference was noted, the plaster having hardened sufficiently during the shorter interval to transmit the pressure perfectly. This method has, therefore, compared to that in which cubes are ground out of the brick, the advantage of cheapness and speed, and with nearly as good results, probably within the percentage of error of the sampling and of the machine.

Half bricks from the transverse test were also used for the absorption test. They were first dried thoroughly in a steam closet for twenty-four hours, then after weighing were immersed in water. They were allowed to remain in the water for forty-eight hours, after which they were taken out, the surface water wiped off, and reweighed. The percentage absorption is then calculated,

[1] A. Marston; Iowa Geol. Survey, Vol. XIV, p. 573.

based on the weight of the dry brick. It has been shown, especially well by Professor Marston in the excellent series of tests made for the Iowa Geological Survey, that the the bricks are not completely saturated at the end of forty-eight hours, but that this seems to be the most favorable period to stop the experiment for purposes of comparison, instead of dragging it out any longer. The absorption is also better obtained from half bricks than from whole, as the surface of a well burned brick is denser than the interior and it acts as a more or less impervious covering.[1]

The following table shows the results of the tests. The names of the manufacturers are not published, in accordance with the promise made to them. Each one had been informed, however, as to the results of his own product.

TABLE OF PHYSICAL TESTS ON NORTH DAKOTA BRICK.

Transverse strength, modulus of rupture lbs. per sq. in.	Compressive strength load at rupture lbs. per sq. in.	Compressive strength load at crushing lbs. per sq. in.	Absorption per cent	Character of brick
SOFT MUD BRICK.				
471	1620	1920	22.1	Normal.
827	1120	1762	24.3	Normal.
780	1450	2280	23.2	Normal.
1280	1468	3130	19.2	Normal.
1204	1560	1950	23.9	Normal.
1740	3160	3350	17.9	Hard burned.
506	1333	1333	28.6	Normal.
....	1067	1600	23.0	Normal.
767	965	1319	16.9	Normal.
152	473	630	20.5	Normal.
589	762	1524	15.2	Normal.
667	800	1466	17.0	Normal.
690	2280	2420	17.1	Repressed.
540	707	883	25.7	Normal.
106	1060	1338	14.8	Normal.
218	1380	1760	19.3	Normal.
225	1420	2840	22.3	Normal.
1010	2750	2900	19.8	Normal.
STIFF MUD BRICK.				
1156	970	1940	14.4	Normal.
513	3333	4333	19.1	Normal.
1690	1200	2400	2.0	Hard burned.
1070	760	2300	8.5	Normal.
DRY PRESS BRICK.				
209	1700	2040	21.8	Normal.
1270	3040	4250	11.8	Normal.

[1] H. Ries: New Jersey Geol. Survey, Vol. VI, p. 253.

Transverse strength, modulus of rupture lbs. per sq. in.	Compressive strength load at rupture lbs. per sq. in.	Compressive strength load at crushing lbs. per sq. in.	Absorption per cent	Character of brick
1018	4250	6050	11.5	Normal.
980	4130	5900	9.8	Normal.
1039	4563	6711	11.3	Flashed.
655	2660	4600	17.3	Normal.
650	3750	6200	14.5	Normal.
....	3120	6250	11.6	Normal.
356	2160	2620	14.5	Normal.
392	2540	3320	14.7	Normal.
415	1670	3350	14.0	Normal.
775	1880	3750	15.0	Normal.
400	1980	2370	13.6	Normal.
658	1612	1934	10.9	Normal.
475	2940	3350	10.8	Normal.
827	3370	4761	11.7	Normal.
1051	4000	6666	8.6	Normal.
313	1600	1600	15.6	Normal.
486	860	1204	9.0	Flashed.

The transverse test is generally conceded at present to be the most valuable strength test. A brick rarely fails by crushing. The pressure at the base of very tall buildings is given as about 157 pounds per square inch.[1] But it does fail sometimes by cracking, the brick being so laid that it is loaded above its elastic limit. The transverse test is also quickly and cheaply made and brings out imperfections in the structure of the brick better than any other test.

The transverse strength of the North Dakota common soft-mud brick given as the modulus of rupture in pounds per square inch ranges from 1,740 to 106 pounds. The highest figure was obtained from a hard-burned brick which did not represent the average product, so that 1,280 pounds is a more correct maximum figure. The average, leaving out the highest figure, is 627 pounds. The stiff-mud brick have a tensile strength of from 513 to 1,690 pounds, the average being 1,107 pounds. The dry-press front brick show a variation in the modulus of rupture between 209 and 1,270 pounds, 742 pounds being the average. The results of these tests compare well with the tensile strength of brick made in other states. The New Jersey[2] common soft-mud brick range from 141 to 1,042 pounds with an average of 571 pounds, and the stiff-mud brick from 513 to 1,750 pounds, the average being 950 pounds. It should also be borne in mind that the poorer products are from the small plants which produce but a small proportion of the total output. The

[1] Wisconsin Geol. Survey, Bulletin IV.
[2] New Jersey Geol. Survey, Vol. VI. p. 258.

average for the dry-press brick is rather low, but fire brick are included under this head, which have not a sufficient bond to give a high tensile strength.

The crushing test is not of the greatest value and does not represent the true wearing qualities of the brick. As stated above, a brick rarely fails by crushing when first laid, but it may after having been subjected to the weather. Therefore, the crushing strength is of more value after the brick has been repeatedly frozen and thawed. Lack of time prohibited the carrying out of freezing and thawing tests on North Dakota brick.

The crushing strength of the North Dakota soft-mud brick ranges from 3,130 to 630 pounds per square inch, with an average of 1,827 pounds; the stiff-mud brick between 4,333 and 1,940 pounds per square inch, the average being 2,743 pounds; and the dry-press brick between 6,666 and 1,204 pounds, the average being 4,359 pounds. These figures are somewhat lower than the crushing strength tests of brick in other states. The average for the common soft-mud New Jersey brick, given by Ries,[1] is 3,703 pounds, the stiff-mud 4,856 pounds, and the dry-press 9,992 pounds. The West Virginia building brick range from 1,700 to 6,500 pounds,[2] and the Iowa[3] common brick from 5,180 to 1,470 pounds, with 3,065 pounds as the average. The crushing strength of the dry-press front brick[4] tested by the Iowa Survey varies from 17,500 pounds to 5,500 pounds with an average of a little under 8,000 pounds. The low results of North Dakota brick may be accounted for partly by the mthods used in testing, the other states using ground cubes to break.

Undoubtedly the crushing strength of most of the North Dakota brick is low on account of their high porosity and insufficient burning. The porosity of most of the brick is very high, as shown by the table, and there is some relation between the absorption and crushing strength. Some of the best bricks, with high tensile strengths, but which also have a high absorption, have lower crushing strengths than some of the soft, underburned, denser bricks which are of poorer grade. Also most of the common brick are burned in scove kilns and are underburned, this being especially true of the brick from the smaller plants. The tests of the hard-burned soft-mud brick (sixth in the table) show well the need and

[1] N. J. Geol. Survey, Vol. VI, p. 256.
[2] W. Va. Geol. Survey, Vol. III, p. 288.
[3] Iowa Geol. Survey, Vol. XIV, p. 595.
[4] Ibid, p. 562.

value of burning the brick harder than is done at present. The laminations in the stiff-mud brick account partly for their low crushing strength.

The crushing strength of the dry-press front brick have a rather low average compared to those from the other states. This average is, however, lowered by including some fire brick with a weak burn, and some improperly burned brick burned in scove kilns. The strength of the best front brick could be improved at a sacrifice of color and material. At present the very best refractory clay is used, so that the brick are practically fire brick, but have not the bond which should be developed in a clay of lower fusibility. The color of these brick is excellent, and as the strength is satisfactory no change in material would be advisable. The tendency toward the use of too much and too coarse grog should, however, be avoided.

The absorption test gives the amount of pore space, but fails to take account of the structure and the size of the pores, and is therefore of little value. The crushing strength and absorption seem to have some general relation to one another, this relation being especially well shown in the tests on the dry-press brick. The absorption of the North Dakota common brick is high (28.6 per cent to 15.2 per cent), with an average of 20.6 per cent for the soft-mud brick; and 19.1 per cent to 2.0 per cent, with an average of 11.0 per cent, for the stiff-mud. The average of the New Jersey soft-mud brick is 13.4 per cent[1] and of the stiff-mud 10.2 per cent. The West Virginia building brick gave from 4.1 to 16.5 per cent[2] absorption; and the Iowa common brick 9.5 per cent to 22.7 per cent, with an average of 17.0 per cent.[3] The high absorption does not seem to affect the wearing qualities and tensile strength of the better class of brick, although it does the crushing strength. A lower absorption would be obtained by harder burning than is practiced.

The absorption of the dry-press brick is not much higher than in those from other states, ranging from 21.8 to 8.6 per cent, with an average of 13.0 per cent. The absorption tests made on several makes of dry-press bricks by the Iowa Survey showed a variation of from 4.5 per cent to 18.5 per cent, the average being about 10.0 per cent. A moderate absorption is not harmful if the pores are of sufficient size to allow the water to expand in them when it

[1] New Jersey Geol. Survey, Vol. VI.
[2] W. Va. Geol. Survey, Vol. III.
[3] Iowa Geol. Survey, Vol. XIV.

freezes. A porous brick becomes dirty more quickly than a denser one and there is also some danger from drying the mortar too quickly in laying porous brick.

The tests on the North Dakota brick showed that there is room for considerable improvement in the common brick, especially in those of the smaller plants. This may be accomplished by a more careful preparation of the clay and by harder burning. Some of the dry-press brick, however, rank with the very best made in the country.

STATISTICS OF PRODUCTION.

The value of the clay products produced in North Dakota in 1905 was as follows:

	Thousands	Value	Av. Price
Common brick	24,864	$193,036	$ 7.74
Dry-press brick (includes front, fire and ornamental brick)	1,562	22,294	14.27
Hollow bricks and blocks, special shapes and fire clay		2,241	
		$217,571	

The number of men employed by the clay industry in 1905 was 422. The number of months during which the plants were in operation varied from two to nine, the average of time of operation being four and a half months. There were nineteen plants running, eleven of which employed power, the total horse power of the engines used being 711. Six of the plants used lignite for fuel.

DIRECTORY OF NORTH DAKOTA BRICK PLANTS.

NAME OF FIRM	LOCATION	PROCESS	PRODUCTS
Brose & Son	Abercrombie	Soft-mud	Common Brick
State Brickyard	Bismarck	"	" "
Mouse River Lignite Coal Co,	Burlington	"	" "
Dickinson Fire & Pressed Brick Co.	Dickinson	Stiff-mud dry-press, repress	Common, front, fire and ornamental brick and especial fire clay shapes
Drayton Brick Co.	Drayton	Soft-mud	Common Brick
Anderson Bros.	Fargo	"	" "
Fargo Brick Co.	"	"	" "

NAME OF FIRM	LOCATION	PROCESS	PRODUCTS
Grand Forks Brick, Tile & Cement Co.	Grand Forks	Soft-mud	Common Brick
Red River Valley Brick Co., Alsip Dinnie & Hunter yards	"	"	" "
Hebron Fire & Pressed Brick Co.	Hebron	Dry-press, soft-mud and repress	Common, front and fire brick. Special fire clay shapes
Hillsboro Brick & Tile Co.	Hillsboro	Soft-mud	Common Brick
Kenmare Hard Coal, Brick & Tile Co.	Kenmare	Stiff-mud, dry-press	Common and front brick; hollow brick
Mandan Hand Made Brick Co.	Mandan	Soft-mud	Common Brick
Mayo Brick & Tile Co.	Mayo	Stiff-mud, dry-press	Common, front and hollow brick; hollow block and drain tile
Minot Brick Co.	Minot	Soft-mud	Common Brick
Omemee Brick Co.	Omemee	"	" "
C. S. Bowser	Richardton	Soft-mud and dry-press	Common and front
Rolla Brick Co.	Rolla	Soft-mud	Common Brick
Broegger Mercantile Co.	Williston	"	" "
Washburn Lignite Coal Co.	Wilton	Soft-mud and dry-press	Common, front and hollow brick

FUTURE OF NORTH DAKOTA INDUSTRY.

The outlook for the brick industry of North Dakota is promising, and there will undoubtedly be a steady and gradual increase of production. The demand for common brick will come from the rapidly growing cities of the region, and the state should become an exporter of high grade front, fire and ornamental brick. The growth of the industry to date has been gradual, as shown by the figures given in the "Mineral Resources," published by the United States Geological Survey.

VALUES OF CLAY PRODUCTS (BRICK) IN NORTH DAKOTA FROM 1895–1904.

1895	1896	1897	1898	1899
$48,000	$59,625	$62,420	$72,900	$168,124
1900	1901	1902	1903	1904
$92,399	$76,708	$141,214	$127,085	$147,579

The production in 1905 was $217,574. This figure was determined by statistics collected by the State Survey and is thought to be approximately correct. The establishment of three new plants, located at Grand Forks, Hillsboro and Wilton, and the organization of a new company at Dickinson during the last year (1906) and those at Mayo and Hebron the year before, reveal the progress

that is being made. The season of 1906 was the most successful in the history of the state and the value of the total production probably reached in the neighborhood of $300,000, if not over.

The season of 1907 promises to be even more successful than the past, as some of the largest plants have only just completed their equipment. In the northern and eastern parts of the state there is a strong demand for front brick. In the southern and western parts of the state there is on the other hand a greater need of common brick. This demand can be supplied by home manufacturers. The establishment of new plants will undoubtedly increase with the growth of the state but they should not be unduly encouraged, since brick can be more satisfactorily made, both from the standpoint of economy and grade of brick, by larger manufacturers with a good equipment. Therefore, the improvement of methods, especially in the matter of burning, and the enlargement of the existing plants is most desirable.

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